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SECRETARY



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PREFACE.

THE present volume of the *Journal of the Iron and Steel Institute* contains the report of the proceedings at the Autumn Meeting of the Institute, held at Paris in September 1921, together with the papers presented, the discussion and correspondence thereon, and an account of the Entertainments, Visits, and Excursions during the Meeting in France.

Section II. contains, as usual, Notes on the progress of the iron and steel industries at home and abroad as reported in the proceedings of Scientific and Technical Societies, and in the Technical Press, together with a Bibliography of the principal works dealing with the metallurgy of iron and steel, mining and allied subjects which have appeared during the past six months.

28 VICTORIA STREET, LONDON, S.W. 1.
December 31, 1921.

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THE
IRON AND STEEL INSTITUTE.

SECTION I.

MINUTES OF PROCEEDINGS.

PARIS MEETING.

THE AUTUMN MEETING of the IRON AND STEEL INSTITUTE was held in the Lecture Theatre of the Comité des Forges de France, 7 Rue de Madrid, Paris, on Monday and Tuesday, September 5 and 6, 1921.

In the regrettable absence of Dr. J. E. Stead, F.R.S., President, through ill-health, Sir Hugh Bell, Bart., Past-President, occupied the Chair. The Secretary formally submitted the minutes of the last meeting, which were approved, and read out the names of the following Vice-Presidents and Members of Council, who, in accordance with Bye-Law 10, were due to retire in May 1922, but who were eligible for re-election. These were : *Vice-Presidents*—Mr. Andrew Lamberton, Mr. E. Steer, and Mr. W. H. Hewlett. *Members of Council*—Mr. G. Trasenster, Mr. G. Hatton, Mr. B. Talbot, Mr. H. Brearley, and Professor Henry Louis.

Mr. FRANÇOIS DE WENDEL (President of the Comité des Forges de France), speaking on behalf of his colleagues of the Comité des Forges, said it was a great pleasure and honour to be called upon, as President of the Comité des Forges, to welcome the members of the Iron and Steel Institute who had accepted the hospitality of the Comité for their Autumn Meeting.

Such an event had not taken place for over twenty years. The last meeting in France was in 1900, at the time of the Paris 1921—ii.

Exhibition, and, by a happy coincidence, it was a member of his (Mr. de Wendel's) family who was President of the Comité des Forges and had greeted them on that occasion. The most cordial relations had always existed between his family and leading British metallurgists, and those relations had extended even to their families, as Sir Hugh Bell, whom he was gratified to see was acting as President, would bear him out. He might also remind the members that his brother, Mr. Humbert de Wendel, had, during the war, been brought into touch in London with many prominent British ironmasters. He ventured to believe that the welcome that he, on behalf of his colleagues of the Comité des Forges, tendered the members of the Institute that day, after a long and cruel war, during which both countries had fought side by side upon French battlefields, was no less cordial than that which he and his colleagues had extended in the past.

The visits which some of the members, particularly those who proposed to proceed to Lorraine, were about to make would afford them opportunities for studying not only the technical or economical conditions prevailing, but also the political factors upon which the prosperity of the country depended. They would be able to study those questions to greater advantage during their short stay in France than they could hope to do at a distance, and would realise better the important problems that arose along the frontiers of the district they would visit.

It would be foolish to disguise the fact that there had been at times strong divergencies of opinion between the respective governments of the two nations. He would not discuss those matters, but he would ask the members to do their best to understand the French point of view during their visit to France. It was the point of view of a people who did not enjoy the privilege of being, like Great Britain, separated from Germany by that silver circle which girdled the British Isles. He would also ask them to remember, when visiting the devastated factories in Meurthe et Moselle, that such efforts as had been made in the direction of reconstruction had been made with French money and not at the expense of the authors of that destruction, whose works were even at that moment successfully competing for the commercial conquest of the world. The French point of view—having regard to the imminence and the permanence of the dangers that faced them—could not be the same as that of any other

nation whose territories had remained intact, and whose security was unmenaced. It might be that there were those in England who thought the dangers exaggerated. He could only hope that what he had said might lead them to examine the problems on the spot, and to take into consideration the hopes and fears of his own country. The cordial friendship of England and France appeared to him to be the best possible guarantee for the future peace of the world.

Sir HUGH BELL, in response, said that, to begin with, he had to apologise for occupying the chair. The illness of their revered President, Dr. Stead, prevented his attendance in Paris, and his (Sir Hugh's) colleagues had invited him to take Dr. Stead's place. The members would doubtless agree with the wish already expressed by the Council to send a telegram to Dr. Stead, conveying their deep regret at his absence and their best wishes for his restoration to health.

The meeting having unanimously endorsed that recommendation,

Sir HUGH BELL, continuing, said he thanked Mr. François de Wendel most heartily for the very kind words of welcome he had expressed. They, as ironmasters, were always sure of a welcome from their French colleagues. His own relations with the French iron and steel trade went back to those early days to which Mr. de Wendel had alluded. His first acquaintance with Mr. de Wendel's family was made more than fifty years ago. In 1869 he had travelled in France in company with the grandfather of the present President of the Comité des Forges, and he still had a very vivid recollection of a prophecy which the late Mr. de Wendel made that there was going to be a war between France and Germany, adding that the first encounters would probably take place on the very ground they were then traversing. Unhappily within two years of that visit the prophecy proved true.

He (Sir Hugh Bell) looked back through a long series of years of friendly, and he thought he might almost affirm affectionate, intercourse with the family of Mr. de Wendel, and he wished to make a similar reference to another great family in France,

namely, that of Mr. Schneider, whom they were very glad to have as a member of their Council. They were always certain of a welcome in France, but their host had omitted to remind them, perhaps for good and sufficient reasons, that they were on the eve of making a visit to France in that year of terrible memory, 1914. All the arrangements had been made for the forthcoming Paris Conference, but circumstances which had now become a bitter memory, prevented that visit. And now they looked back over those seven years of deep disaster not only to the beautiful country of France, but also to the world at large, a disaster the fullest extent of which they were even now hardly aware. The duty had been cast upon them all equally, British and French alike, to do all in their power to repair as early as possible the disasters which befell the world after the declaration of war in 1914.

He agreed with Mr. de Wendel that it was no use disguising from themselves the facts, and he would venture to commend the admirable discretion which the President of the Comité des Forges showed in dealing with that difficult and delicate subject. That was not the place for political discussions, nor was it desirable that he (Sir Hugh) should traverse, in any contentious spirit, the very gracious language which had been adopted by Mr. de Wendel. It was inevitable that there should be some divergence of opinion between people situated on the other side of that silver streak already referred to and those actually living on the Continent of Europe. The war was nothing but an evil, but let them hope that there might be found some spirit of goodness even in that evil thing, and that the new conditions which had been brought about might render it possible for them to regard one another in a spirit somewhat different from that which prevailed prior to 1914.

France must almost of necessity take a completely different position in the commercial world in consequence of those changes, and it would be for the nations of Europe to determine—especially those who were most deeply interested—exactly what that position should be. He would venture to affirm on behalf of Great Britain that nothing would be wanting on their side to make for France the very best of the difficult situation and to make that position as advantageous and as profitable as might be.

Mr. de Wendel had referred to the large and active population which was to be found on the further side of the eastern frontier of France. Well, Englishmen on their part must not lose sight of that fact. He hoped that their eyes had been opened to the true situation. Might they hope, though perhaps less sanguinely, that the eyes of the Germans had also been opened, and that they too had learnt that of all bad ways by which to obtain commerce war in any form was the worst? It was only by the earnest co-operation of all engaged in industry that they might hope to return to the situation in which they found themselves in 1914, from which they had fallen away, and so produced disasters of the exact extent of which they were hardly yet conscious. He was sure those present would understand the deep sympathy which the British members of the Institute felt, and which he desired on their behalf to express, with the French in the calamities which had befallen them. He desired also to express their sincere wish for the speedy reparation of the damage which had been done and for the return to the prosperity which they so richly deserved. In that prosperity, as well as in that of Great Britain and of other countries, lay the hope of the world. Perhaps, therefore, it was not inappropriate that, in that first Iron and Steel Institute meeting which had taken place on the Continent since the war, some expression should be given with regard to those circumstances to which Mr. de Wendel had already referred.

The metallurgical industry, while it was, alas, as they knew too well, the chief instrument of warfare, was also the chief instrument of peace. Let them hope that, having in the past changed their ploughshares into swords, they were now transferring them back again to their more peaceful and useful purpose, and that neither within the experience of their children, their grandchildren nor great grandchildren would the peaceful ploughs ever be again changed into instruments of war.

TESTIMONIAL TO PROFESSOR LE CHATELIER.

Sir HUGH BELL said that before the papers were opened for discussion he had a pleasant duty to perform. He had invited

Professor Le Chatelier to take his place at the table, and he knew how warmly they would welcome their venerable friend. His own acquaintance with the family went back as far as the year 1859, when he had the honour of meeting Mr. Le Chatelier's father. It was in that year that the French armies returned victorious from the campaign in Italy. He (Sir Hugh) happened also to be in Paris in the year 1918 when he had the pleasure of seeing the representatives of the Allied Armies pass before the President of the French Republic. Professor Le Chatelier was an old member of the Institute and a very distinguished man of science. That fact was going to be commemorated. The Council had asked permission to become contributories to the fund which had been raised for the purpose of commemorating Professor Le Chatelier's jubilee, and it afforded him very great satisfaction to make that announcement to the meeting. He would take that opportunity of offering personally his own sincere congratulations as well as those of the Council on Professor Le Chatelier's celebration of the jubilee of his connection with the School of Mines at the Sorbonne.

Mr. H. LE CHATELIER, Member of Council, said he retained a very strong recollection of Sir Lowthian Bell, the great English metallurgist, by whom he (Professor Le Chatelier) had been received in Middlesbrough as far back as 1868, when he was pursuing his earliest studies in metallurgy. He had also met Sir William Siemens, who had been a friend of his (Professor Le Chatelier's) father. In those circumstances he might say that from his early youth he had been in contact with two of the most eminent metallurgists of Great Britain. He had subsequently embarked on scientific investigations which had led him more particularly to study the effect of high temperatures, and it was at a much later date that the influence of his acquaintance with the British metallurgists to whom he had referred led him to take up other investigations. This was about the period when he had founded the *Revue de Métallurgie*.

It was with great pleasure that he found himself associated at that meeting with the son of Sir Lowthian Bell, who, he might say, had worthily followed the traditions of his father, and to whom he (Professor Le Chatelier) wished to express his hearty thanks for the kindly references made to himself.

PRESENTATION OF THE BESSEMER MEDAL.

Sir HUGH BELL said his next duty was, on behalf of the Council of the Institute, to present the Bessemer Medal to Mr. Charles Frémont. He thought his title to that medal was quite indisputable. To his scientific achievements he added practice, and he had rendered great services by his researches in regard to steel, particularly in the matter of testing. Those researches were of a profound and far-reaching character. He would ask Professor Louis to read a note giving in detail an account of the services rendered by Mr. Frémont.

Professor H. LOUIS, Member of Council, speaking in French, said that Mr. Frémont had earned renown by his technological investigations and by his researches on testing. By his experiments and observations he had explored and shed light on metallurgical problems which until then had been unexplored. He had the gift not only of being able to employ most up-to-date and accurate means of research, but likewise of being able, when occasion arose, to improvise appliances and nevertheless to derive, from apparatus of a rudimentary nature, results equally accurate, thus showing that success in research did not necessarily depend upon the possession of a well-equipped laboratory, but that personal capacity and idiosyncrasy were important factors in research. In 1890 Mr. Frémont published his first experiments on the technology of forging operations, and more particularly on the work absorbed during forging. Since that date he had successfully applied the cinematograph to the analysis of the movements of the tup in the work of forging, a remarkable piece of work which was reproduced in 1906 by the Société d'Encouragement. At a later date he conceived the brilliant idea of using elastic deformation as a means of registering stresses, and published numerous diagrams relative to tensile testing, besides a note, communicated to the Academy of Sciences, on the relation between shearing tests and tensile tests.

Mr. Frémont's investigations led him to devise an accurate method of estimating brittleness, a property which at the time of his experiments was still involved in some uncertainty. As the result of numerous investigations, he adopted the plan of breaking the test-pieces by a single blow from a drop weight,

the remanent energy of which was absorbed and measured by the compression of a spring. The machine by which he carried out those tests was now well known throughout the world as the Frémont Testing Machine, and had been universally adopted for the testing of rails, particularly by the leading railway companies. It might be said that, owing to his investigations, the number of cases in which fractures occurred through defective parts had been considerably diminished. In addition to the experiments enumerated, Mr. Frémont also carried out investigations on the resistance of riveted parts; on the testing and manufacture of files, and on many other subjects, and had greatly enriched the knowledge of methods of testing by his lectures, his laboratory work, and his published results.

Mr. FRÉMONT having suitably acknowledged the presentation, papers by Mr. P. Nicou on "The Iron Ore Deposits of Eastern and Western France," and by Mr. A. Guillaïn on "The Iron Ore Mines of the Briey Region Damaged during the German Occupation, and their Reconstruction," were then read and discussed, and the proceedings were thereupon adjourned until the following day, when

Sir HUGH BELL announced that Mr. W. R. Makepeace (London) and Mr. C. A. Ablett (Penarth) had, on the previous day, kindly consented to act as scrutineers of the ballot, and that as the result of the report he was able to announce that the following sixty candidates for membership and nine candidates for associateship had been duly elected.

MEMBERS.

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Ehn, Erik Wilhelm .	Timken Roller Bearing Co., Canton, Ohio, U.S.A.	M. H. Schmid, H. W. McQuaid, M. T. Loth- rop.
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Jones, Thomas William	14 Brynmill Crescent, Swansea	George Rowe, L. Davies, D. Lewis.
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McLain, David	808 Goldsmith Building, Milwaukee, Wis., U.S.A.	A. W. Gregg, W. W. Cole- man, N. P. Hulst.
McQuistan, Andrew Nisbet	Messrs. Cochrane & Co., Ltd., Ormesby Iron- works, Middlesbrough	B. Talbot, J. E. James, H. Ballard.
Mayrisch, Emile	Colpach, Luxemburg	E. Schneider, P. Wurth, H. Coqueugnot.
Merica, Paul Dyer, Ph.D.	The International Metal Co., Bayonne, N.J., U.S.A.	W. Campbell, G. K. Bur- gess, B. Stoughton.
Meyer, Aloyse	Luxemburg	E. Schneider, P. Wurth, H. Coqueugnot.
Miles, John, M.C.	Lane End House, Chapel- town, near Sheffield	C. H. Desch, F. C. Thomp- son, H. Brearley.
Moore, Albert James	Brookland, Langloan, Coatbridge	T. B. Rogerson, W. Buchanan, A. M. Shaw.
Norbury, Allan Leslie, M.Sc.	University College, Swan- sea	C. A. Edwards, J. H. Andrew, H. I. Coe.

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Rogerson, Edgar Holli- day	Société Normande de Métallurgie, Monde- ville, Caen, France	L. E. Deslandes, W. Buchanan, T. B. Roger- son.
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Sandelin, Hjalmar Folke	c/o Messrs. S. K. F., Ind., Inc., 165 Broadway, New York City, U.S.A.	Sir R. A. Hadfield, Bt., J. A. Brinell, C. Bene- dicks.
Sanders, Cecil Mont- gomery	139 Fenchurch Street, London, E.C. 3	E. Steer, B. Talbot, Col. Sir W. Charles Wright, K.B.E.
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Stones, Frank .	125 W. Rensselder Street, Bucyrus, Ohio, U.S.A.	Sir R. A. Hadfield, Bt., I. B. Milne, H. D. Hibbard.
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Thomson, Thomas .	5 Frodingham Road, Scunthorpe, Lincs.	E. C. Greig, J. Hender- son, A. Croke.
Trasenster, Emile .	Boulevard Piercot 30, Liège, Belgium	G. Trasenster, L. Greiner, H. de Gorski.
Turnock, Capt. John Meyric	Bryn Cottage, Cwmavon, Port Talbot, S. Wales	Col. Sir W. C. Wright, K.B.E., T. Crosby, H. L. Davies.
Walmsley, Ben .	Skeynes, Edenbridge, Kent	Sir F. Mills, Bart., A. Lennox Leigh, W. Simons.
Wright, Alfred Fitz- herbert Melville	The Grange, Butterley, Derby	G. F. Wright, G. D. Patten, J. A. Martin.

ASSOCIATES.

Bailey, Ivon Arthur .	20 Wigfull Road, Eccle- sall, Sheffield	C. H. Desch, F. C. Thomp- son, W. H. Hatfield.
Handford, Cecil .	485 Barnsley Road, Sheffield	C. H. Desch, F. C. Thomp- son, J. H. G. Mony- penny.
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Herbert, Thomas Mar- tin	Breck Meadow, Chapel- en-le-Frith, Derbyshire	C. A. Edwards, M. Cook, H. I. Coe.

NAME.	ADDRESS.	PROPOSERS.
Holmes, Albert Baden	"Killygordon," Mossfield Road, Kings Heath, Birmingham	T. Turner, T. Vickers, H. S. Kipling.
Lewis, Dartrey, B.Met.	108 Brincliffe Edge Road, Sheffield	C. H. Desch, F. C. Thompson, A. Deighton
Vickers, Geoffrey Kenneth, B.Sc., B.Met.	Ivy Cottage, Clifton Road, Sutton Coldfield, Warwickshire	T. Turner, T. Vickers, J. E. Fletcher.
Wakley, Henry Weston	Sandsfoot Villa, Rodwell, Weymouth	J. E. Stead.
Young, J. . . .	8 School Lane, Leyland, Lancs.	W. Hardy, C. C. Hodgson, H. Gummer.

PRESIDENT-ELECT.

Sir HUGH BELL said that, in the regrettable absence of Dr. Stead, it was his pleasure and duty to announce that the Council had nominated Mr. Francis Samuelson, Vice-President, for the Presidency, and that Mr. Samuelson's term of office would commence at the May Meeting, 1922. He was sure that those present would join him in cordially wishing Mr. Samuelson a most successful term of office.

Papers by Mr. L. Guillet on "The Position of the Metallurgical Industries of Northern and Eastern France," by Mr. E. Schneider on "The Investigation of Hot-Drawing on the Mandril," by Mr. E. L. Dupuy on "An Experimental Investigation of the Mechanical Properties of Steel at High Temperatures," and by Mr. A. M. Portevin and Mr. P. Chevenard on "The 'Characteristic Curves' of the Heat Treatment of Steels," were then read and discussed.

Sir HUGH BELL said that before closing the proceedings he had a sad announcement to make. No doubt members would recall that they had had the honour of counting among their honorary officers Professor D. Tschernoff, who was an honorary Vice-President. The Council had learned some time ago of the very distressing situation in which Professor Tschernoff found himself in the Crimea, and they had now learned of his death, the news of which had been brought by Colonel Belaiew. He

felt sure the members of the Institute would wish to record their sincere condolence with the family of their colleague. Every student of metallurgy was under the deepest obligations to Professor Tschernoff. His main work on which his fame rested was his research on the critical point of steel, his first book on that subject having been published fifty years ago (in 1868), when he described the critical points alpha and beta, which were of such vital importance to every steelmaker.

Sir HUGH BELL said that before they closed the meeting he would ask those present to tender their warm thanks to the Board of the Comité des Forges and to the Secretary, Mr. Robert Pinot, for all that they had done to make the visit a success, and for the excellence of the arrangements made for the entertainment of the visitors as well as for their instruction.

Sir ROBERT HADFIELD, Bart., F.R.S., Past-President, said he had great pleasure in seconding Sir Hugh Bell's proposal. Nothing more could possibly have been done than had been done, and they all greatly appreciated the kind efforts made for their profit and pleasure. They were about to visit the chief centres of the metallurgical industry of France and would continue everywhere to receive great kindness. It was with the greatest possible pleasure that he put the resolution to the meeting.

The resolution was carried with acclamation.

Mr. ILLTYD WILLIAMS, Honorary Treasurer, moved that a cordial vote of thanks be passed to Sir Hugh Bell for presiding over that meeting. Owing to the very regretted illness of Dr. Stead they had been obliged to fall back on their tower of strength, Sir Hugh. It was by no means the first time that the Institute had been indebted to him under similar circumstances, and they knew he was always ready to help when occasion arose.

The motion was carried with acclamation.

Sir HUGH BELL having briefly responded the proceedings terminated.

Iron and Steel Institute.

THE IRON ORE DEPOSITS OF EASTERN
AND WESTERN FRANCE.¹

BY P. NICOU (PARIS).

IN 1914² the Iron and Steel Institute was to have held its autumn meeting in France, and after the meeting excursions had been arranged to the ironworks and mines in the East and in the West, regions which were the more interesting to British ironmasters inasmuch as they were either obtaining, or about to obtain, a very large proportion of their own iron ore requirements therefrom.

The outbreak of the war in August 1914—a war which was to last over four years—prevented the project from being put into execution, so that it is only now, after a lapse of seven years, that the visit of the Iron and Steel Institute to France has become possible.

Many changes have taken place in the relative situations of European iron-making countries within the period comprised between 1914 and 1921. One feature, however, remains the same, and that is the need of Great Britain for foreign ores. These ores she has sought in regions widely distributed, and in these regions she must remain vitally interested in order to ascertain whence, and under what conditions, she can best obtain the ores required for her blast-furnaces.

A fairly considerable import trade in French ores into England had already sprung up before the war, from such ore-fields as were adjacent to harbours, such as those of Normandy, Brittany, and Anjou, for which Caen and St. Nazaire competed with each other. The ores of Algeria and Tunis, whose purity rendered them specially suitable for the manufacture of high-grade pig iron, were likewise arousing interest, as well as those of Lorraine,

¹ The length of Mr. Nicou's original paper, and the exigencies of printing it in time for the Autumn Meeting, rendered it necessary slightly to abridge it. The passages omitted have since been restored.

² The previous memoir contained two maps. See *Journal of the Iron and Steel Institute*, 1914, No. II. pp. 131-164.

amongst which were the richer of the Briey ores, which had already reached those regions of the United Kingdom more particularly engaged in the manufacture of phosphoric pig iron.

During the war the eastern ore-fields of France were unable to be of any assistance to British metallurgy, having been occupied, from the outset, by the German army, and it was not until after the Armistice that the enemy evacuated this district. On the other hand the Algerian, Tunisian, Normandy, Anjou, and Brittany ore deposits supplied British works, if not with very large quantities, with as large an amount as the exigencies of war permitted. Numerous colliers, laden with the coal necessary to French industry, returned with the ore cargoes of which the United Kingdom was in pressing need and found of such value owing to the short distance over which they were sea-borne, which made them less vulnerable than others to the attacks of the enemy's submarines.

Now that circumstances have altered and that France, as the result of the recovery of Alsace-Lorraine, has become, of all the continental nations, the possessor of the largest iron ore resources, it is not surprising that British metallurgists should look once again to France as a source of supply, and that the relations which existed before and during the war should display a tendency to become closer and closer, to the great mutual benefit of both nations.

Great Britain must for many years to come remain dependent upon foreign countries for her ore supply, and if she can find those ores in countries which, during the war, were her allies, she will naturally seek them there rather than in those countries which, as long as the war lasted, evinced marked sympathy with the Central European Powers.

On the occasion of the projected meeting the author was invited to contribute a paper on the iron ore deposits of Eastern and Western France. In the present paper he has brought up to date the data previously given, and described the conditions now prevailing, more especially in the East, as the result of war damage.

To begin with, it may be of interest to compare present day production with the pre-war production, and briefly to sum up the whole situation in regard to the production of iron ore in

France. Recourse will be had, for this purpose, to statistics collected by the Department of Mines, which have been kindly placed at the author's disposal. (The figures for 1920 are provisional only.) In 1913, the latest year for which statistics are not affected by the outbreak of the war, the total production of iron ore in France amounted to 21,917,870 tons, distributed as follows :

	Tons.
Lorraine (Meurthe-et-Moselle)	19,978,937
Normandy	812,984
Anjou and Brittany	399,926
Pyrenees	370,347
Other districts	355,676

The overwhelming proportion contributed by Lorraine is clearly shown by the foregoing figures. It amounted to 91 per cent. To the total just given, in order to compare the outputs for 1919 and 1920, must be added the output of ore-fields of recovered Lorraine, which produced 21,136,265, making a grand total of 43,054,135 tons, produced from districts now wholly French. Of this total the Lorraine deposits produced 95·5 per cent.

Compared with this total, the 1919 and 1920 figures show an enormous falling off. Those for 1919 were only 9,429,789 tons and those for 1920, 13,871,187 tons, and whereas the 1913 production of iron ore from deposits in Lorraine was 41 millions of tons, the 1919 and 1920 figures are only 8,634,526 and 13,072,419 tons respectively. The almost complete destruction of the iron-works of Meurthe-et-Moselle, which was systematically carried out by the Germans, is the chief cause of this falling off. The production of the rich calcareous ores of the Briey field, which in 1913 were mined to the extent of 15,103,849 tons, had fallen in 1919 to 645,245 tons, but recovered considerably in 1920, in which year it reached 3,466,619 tons. The Longwy ore-field suffered similarly, and the output fell from 2,958,167 tons in 1913 to 189,853 tons and 714,610 tons respectively in 1919 and 1920. In other words, these two ore-fields, whose production in 1913 was 18,062,016 tons, did not produce one million tons in 1919, and barely exceeded four million tons in 1920.

Other French ore-fields were similarly affected, although for different reasons. Their production was pushed to a maximum 1921—ii.

during the war, as they were the only productive ore regions in France outside the German occupation. They therefore enjoyed the advantages of a huge demand, and an influx of enormously increased labour recruited from miners from the occupied coal and iron districts, and Moors and Kabyles brought from Northern Africa, and from prisoners of war. From the time of the Armistice these sources of labour have been almost completely withdrawn.

The metallurgical crisis that took place directly after the Armistice owing to the lack of fuel in France similarly served to reduce the orders from home works, and even if some ore-fields escaped lightly, others were seriously affected, as the following figures will show :

Ore Output in other Regions, 1918-1920.

	1918.	1919.	1920.
Normandy . . .	812,984	322,929	357,200
Anjou . . .	399,926	52,211	119,984
Pyrenees . . .	370,347	357,095	213,782
Other localities . .	355,676	63,028	107,802
Totals . . .	1,938,933	795,263	798,768

Reduced demand for ore for export also helped to reduce production. It should, however, be noted that the proportional decrease in Normandy, Anjou, and the Pyrenees, as compared with that of the whole of France, is as 56 is to 66. It should also be pointed out that the falling off in production of iron ore was not confined to the Lorraine portion of the Eastern deposits. The Luxemburg output in 1913 was 7,333,372 tons, whereas in 1919 it was but 3,112,472 tons, and in 1920, 3,704,390 tons, or, taking the latter year as an example, only 50 per cent. of the 1913 production.

LORRAINE.

Although the iron ores of Lorraine, the export of which across channel only commenced in 1912 with 28,014 tons (which rose in 1913 to 69,224 tons), have been a much shorter time on the British market than those of Normandy and Brittany, they are destined, sooner or later, very largely to be laid under contribution by British ironmakers. The ores of this mine-field are doubtless

less favourably situated, from the point of view of transport, than those of Normandy, Anjou, and Brittany, seeing that Homécourt, the northern extremity of the ore-field, or, at any rate, of the export area proper, is 400 kilometres by rail from the port of Dunkerque, and that it is not yet feasible to make use of any waterway which might afford cheaper means of transport. The project of a north-eastern canal which should link up the Longwy metallurgical region with the Ardennes and be in communication with existing waterways, thus improving considerably the local conditions, has been discussed over and over again; but the heavy cost which, in existing circumstances, such a project would entail must render its realisation a matter of time. Meanwhile the Lorraine ore-field will have to rest content with existing means of transport, if cargoes are to be exported from a French port. The canalisation of the Moselle, a project often discussed before the war, which would allow of the transport of the Briey ores to Thionville, whence they could be sent, *via* the Moselle and the Rhine, to Rotterdam, seems likewise of only distant realisation. In these circumstances the low percentage of the Briey ores is an obstacle, in these days of heavy freight charges, consequent on post-war conditions, to any extensive export trade with Great Britain. It could only be on a lowering of these transport costs, and in combination with a return trade in metallurgical coke for use in Lorraine blast-furnaces, that such a trade could have any chance of early development. Its importance is, however, so considerable that many minds have been occupied with its solution.

It has already been pointed out that only the richer ores of the Briey field could constitute the material for an export trade to Great Britain. The situation may be said to resemble very closely that of the Westphalian and Belgian blast-furnaces, for which the question of railway transport becomes increasingly important, and for which therefore it is sought to secure increasingly high percentages of iron in the ores transported.

The author has hitherto spoken only of Dunkerque as the French port of embarkation. This does not mean that no others are available. Calais might be a factor in the solution of the problem, while in Belgium, where the economics of railway administration receive rather more attention than they do in

France, the ports of Bruges, Ghent, and Antwerp might well enter into consideration.

The ores of Lorraine belonging to the great metalliferous formation which was discovered on French territory extends into Luxemburg, and is found, owing to faulting, in Belgium as well. The production of this vast ore-field constituted, before the war, 28 per cent. of the whole world output of iron ore, and was exceeded by only one other deposit, that of the Lake Superior region in the United States.

The French portion of the deposit, now that Lorraine has been completely recovered, is by far the more important, seeing that in 1913 it yielded 41 millions of tons as against $6\frac{1}{2}$ millions in Luxemburg and some tens of thousands of tons in Belgium.

The increase in the production was most marked in the portions of the field most recently opened up, that is, in the Briey basin. This basin, which was only known through a series of boreholes commencing in 1886, and from which extraction commenced as late as 1895, had by 1913 reached a production of 15,103,849 tons out of a total of 20 millions from the whole of French Lorraine, or over 75 per cent.

It owed its rapid development to the fact that the ores are almost wholly found in a single stratum; the grey bed, whose thickness varies from 3 to 5 metres, is uniform over wide areas, and lies at a comparatively small depth from the surface. The iron content varies from 34 to 40 per cent., and the ore presents the usual characteristic of the Lorraine ores, that is to say almost constant proportion of phosphorus. The gangue is usually calcareous.

Before its discovery and opening up the ironworks of Lorraine had to add, to their siliceous ores, lean chalky ores, or even lime, from other regions. They have since been able to use these rich limey Briey ores, thus increasing the iron content of their burden and diminishing their coke consumption. Hence they have been able to compete at far lower prices, and under far more favourable conditions, with other countries.

In what follows a description will be given of the Lorraine basin, and more particularly of the Briey ore-field, that being the district which possesses the greater appeal to British metallurgists.

ORE-FIELD OF OLD FRENCH LORRAINE.

Nancy, Briey, and Longwy.

The older French Lorraine ore-field extends over 168,910 acres, and is divided into 114 concessions, which, from the standpoint of French Mining Law, comprises all that is actually workable. There are still thousands of acres which might form concessions either to the north, in the siliceous ore-field of Crusnes, or to the south, around Nancy and the Forest of Haye. The entire surface may be estimated at 178,000 to 186,000 acres of workable ore as against 106,260 acres in recovered Lorraine, 8890 acres in Luxemburg, and a few hundreds of acres in Belgium. Of the total, two-thirds belonged to France even before the war, and France now possesses 97 per cent. of the entire area.

From a geographical point of view the French areas may be divided into two portions; one, of about 44,500 acres, forming the Nancy ore-field, sharply separated from the other by a sterile zone between Dieulouard and Mars-la-Tour, the latter marking the southern boundary of the northern ore-field. This can, in itself, be divided into four portions: the Orne district in the south, the Landres-Tucquegnieux district farther north (which two regions constitute the Briey ore-field proper), and, in the extreme north, the Crusnes and Longwy ore-fields.

The iron-bearing formation which outcrops in recovered Lorraine on the western slopes of the Moselle, dips westward to a depth of 240 metres below the surface, and at Amermont reaches its extreme western limit of workability. It continues to dip farther west, but becomes too poor to be worked; near Etain and Verdun the iron-bearing formation is encountered at a depth of 580 metres.

Geology of the Ore-Fields.—From the geological point of view the iron-bearing formation forms part of the great Paris basin, bounded on the north and east by the primary rocks of the Ardennes, Eifel, and the Vosges. The different geological periods outcrop as concentric belts of ever increasingly recent date the nearer they approach Paris. In the Meurthe and Moselle the outcropping rocks belong to the Callovian, Bathonian, and Toarcian periods, and it is in the latter zone that the iron-bearing

formation occurs, dipping, as a general rule, towards the west some 10 to 15 millimetres per metre. The ferruginous formation consists of a certain number of beds, which, however, do not all occur simultaneously, and are grouped by geologists under different horizons.

The general view at present is that these groups should be divided into three—the upper, containing the ferruginous chalk and the red seam; the middle, containing the yellow and grey seams; and the lower, containing the brown, black, and green seams. The floor of the mineralised formation is generally clearly defined and consists of a green, sandy and pyritic marl. The roof consists of micaceous Jurassic marls. The thickness of the whole formation varies from 25 to 30 metres, except in the Nancy district, where it rarely exceeds 10 metres.

The seams are not, generally speaking, sharply separated from the bedding rocks, and the mineralised zone passes into the sterile rock, although in parts of the Briey ore-field, particularly in Landres, the grey seam has a sharply defined roof and ends suddenly.

Ores.—The ore is a hydrated oolitic hæmatite formed of a number of small grains consisting of concentric layers, and of varying dimensions. These grains are sometimes only visible under the microscope; at others they may be the size of a grain of millet seed. The filling between the grains is calcareous or siliceous, and it is on the nature of this cementing material that the characteristic chemical properties are due. The oolitic particles are much higher in iron than the cement and in carefully separated portions contain up to 50 per cent. of iron.

The chalky ores are, generally speaking, harder in proportion to their lime content, while the siliceous ores are often friable. In parts of the deposit, and more frequently in the grey seam, the chalk is segregated into flattened lenticular bodies forming nodules much lower in iron, and the separation of which is warranted when they are present in large proportions, thus reducing too greatly the iron content of the ore mass.

The colour of the ore varies from light yellow to grey and from red to green or dull blue, and traces of iron pyrites occur, more particularly in the lower brown, grey, or black seams. Speaking generally, this pyrites causes no trouble during smelting.

The characteristic feature of the ore is the phosphorus content, which for many years prevented its employment. This feature now constitutes one of its greatest advantages. The proportion of phosphorus to iron is, throughout the whole formation, practically uniform, and only varies between 1.7 and 1.9 per cent. It is therefore entirely unnecessary to estimate the phosphorus in works using the ore, or in the resulting pig iron which, as compared with other ores, such, for example, as Swedish, is a great advantage.

The iron content of the ore rarely exceeds, in ore dried at 110° C., 42 per cent., and is generally between 32 and 40 per cent., in the seams mostly worked. It often falls to 30 per cent. or even 25 per cent. in certain ferruginous chalk used as fluxes. In the Briey district the ore usually runs between 36 and 40 per cent. of iron.

The composition is not constant throughout the thickness of the seam, and varies considerably from place to place, particularly where the lenticular chalk bodies occur. The figures given are the averages from a given mine, which the plant installed, and the methods of working a number of places simultaneously, render remarkably regular. As an exception which should be recorded, there has been found, in a particular mine in the Landres ore-field, a kind of coarse lenticular bed 60 centimetres in thickness, formed of a black ore resembling magnetite, this deposit occurring in the middle of the grey bed. The percentage of iron has exceeded 60.

The ordinary ore contains so much moisture and carbonic acid that it loses from 8 to 12 per cent. of its weight on drying at 110° C., and 14 to 24 per cent. on roasting at a dull red heat. Attempts have been made to profit by these properties and to roast some of the ores intended for distant transport so as to avoid carrying a useless load over considerable distances. It would be easy thus to obtain from the Briey basin ores containing over 45 per cent. of iron and sometimes reaching 50 per cent., but the resulting product readily falls into powder as the result of handling and is likewise highly hygroscopic. Hence these attempts had speedily to be abandoned, and at present the ores of Briey and of other Lorraine ore-fields are used entirely in the raw state.

Nancy Ore-Field—The ferriferous formation outcrops in the Nancy basin, in the valleys of the Meurthe and of the Moselle and their affluents, and extends towards the west beneath the Forest of Haye. In the extreme south a vein has been found and a concession granted on the slopes of Sion.

Throughout the whole of the Nancy district only three seams are known—the upper, middle, and lower. Their thickness is, generally speaking, rarely more than 2 metres. They do not occur everywhere simultaneously, nor, when they all three occur, are they invariably all workable.

The ore is usually highly siliceous, containing from 12 to 16 per cent. of silica as against 6 to 9 per cent. of lime. In some localities it becomes calcareous and contains 14 per cent. of lime and 10 per cent. of silica, as in the Forest of Haye deposits. The iron ore percentages are usually low, being about 32 to 34, and rarely exceeding 35 per cent.

From the point of view of iron ore resources the Nancy basin, including areas beneath the Forest of Haye not yet conceded, would appear to contain 200 millions of tons of workable ore. It was the only ore-field which, during the war, remained available, being beyond enemy occupation, and the blast-furnaces and steelworks at Neuves-Maison, Jarville, Maxeville, Montataire, Pompey, and Pont-à-Mousson, which in peace times derived their supplies chiefly from this ore-field, were able to do so during the war, with the exception of those which, like Pont-à-Mousson, were too near the line of fire. Output was naturally greatly reduced, as only French works were deriving their supplies from the ore-field, and foreign works such as those of Belgium and in the Sarre, which were ordinarily customers, and the greater part of the works in the North of France, and connected with the ore-field by waterways, found themselves completely isolated. The production of the Nancy ore-field since 1907 has been as follows :

Tons.			Tons.		
1907	.	1,942,000	1914	.	1,030,000
1908	.	1,963,000	1915	.	118,000
1909	.	1,959,000	1916	.	697,000
1910	.	2,091,000	1917	.	846,000
1911	.	2,041,000	1918	.	527,000
1912	.	1,974,000	1919	.	669,000
1913	.	1,917,000	1920	.	816,000

Before the war, the export trade accounted for 14 to 17 per cent. of the output. Thus, in 1913, 106,000 tons were sent into Belgium and 237,000 tons into the Saar.

Briey Ore-Field.—North of the Nancy ore-field, and after traversing the sterile zone extending from Dieulouard to Mars-la-Tour, comes the Orne district, the southern portion of the Briey ore-field. Even the oldest concessions in this ore-field only date back to 1875, whereas the principal concessions in the Nancy ore-field have been exploited since 1848 and 1870. It was not that the ferruginous formation was unknown, seeing that before the war of 1870–71 concessions had been granted all along the hills to the west of the Moselle in the region which was then French. At this date, however, the opinion was generally held that the iron ore formation did not extend greatly on either side of the outcrops, and that no important extensions could be looked for in the Arrondissement of Briey, the only portion of the department of the Moselle which remained French after 1871, with the exception of the northern portions around Longwy, where the outcrops were met with in French territory.

This theory long held sway without challenge, and it was only when boreholes had established the presence of workable deposits much farther back than their outcrops in Lorraine, and even beyond the new frontier of 1871, that, in 1875, the first concession was granted. This was the Bois de Briey concession, no longer known by its old name and now merged into more recent concessions.

Unfortunately, the information furnished by a borehole at Chevillon having been misinterpreted, the old theory obtained fresh support, and several years passed before new concessions were granted, between 1882 and 1884, at Fillière la Grange (now merged with the Joeuf concession), at Bois d'Avril, Moutiers, Homécourt, and Auboué. These concessions were the result of investigations carried out in annexed Lorraine, in the concessions at Moyeuivre and Hayange, and borings made by de Wendel and the companies of Vezin-Aulnoye, Gorcy, and Pont à Mousson, in Meurthe-et-Moselle.

Stimulated by these results investigations were continued, and from 1886 to 1902 an entire region, ultimately known as that of the Orne, established the western boundaries of the deposits,

while in the north a boring skilfully carried out in 1894 at St. Pierremont revealed an important deposit. As the result of this last find a whole series of boreholes were laid down towards the west, and led, between 1895 and 1902, to the concession of mining lands in the two districts of Tucquegnieux, along the frontier as far as Audun-le-Roman, and Landres, towards the west. The three subdivisions of Landres, Orne, and Tucquegnieux were therefore fully outlined by 1902, and since this period only a few secondary deposits have been found along the boundaries of those already known, and without any very important results so far as future developments are concerned. The three regions referred to may now be described in further detail.

Orne Ore-Field.—The Orne ore-field, the oldest known and worked, is situated to the south of the Avril fault. Shafts were opened in the following order: Homécourt (Fond de la Noue), 1897; Joeuf, 1896; Auboué, 1900; Moutiers, 1901; Jarny, 1909; Droitaumont, 1910; Valleroy, 1910; and Giraumont, 1914.

The grey seam, which is often the only workable seam, attains an average thickness of 3 to 5 metres, and the ore contains 34 to 40 per cent. of iron. It thins out and becomes leaner on the north-west and southern slopes of the basin. The ore is freely calcareous except in the western region, where the percentage of silica becomes higher.

Amongst other seams known are the green, worked at Homécourt and at Moutiers; the black, near Giraumont; the yellow and red seams at Joeuf and Homécourt; the yellow at Auboué and Valleroy, and the red seam at Moutiers. The lower seams are, generally speaking, the more siliceous, and the upper ones more calcareous. Their iron percentage is distinctly lower than that of the grey seam.

The output of the Orne ore-field constituted, in 1913, 43·2 per cent. of the whole output of the Briey region. It has diminished considerably since the war, the Germans having allowed several of the mines to become flooded, or having rendered them unworkable, which has necessitated, since the Armistice, heavy repair work, besides which the bad mining methods followed by the German engineers have here, as elsewhere, greatly jeopardised the future methods of mining these deposits.

The production, in tons, from these mines is given in the following table :

Year.	Joeuf.	Homécourt.	Auboué.	Moutiers.	Jarny.	Droitaumont.	Valleroy.	Girau-mont.
1905	309,009	883,046	605,154	401,261	...	...	...	...
1906	320,249	1,059,182	912,210	483,783	...	...	...	...
1907	354,548	1,222,296	1,034,075	619,247	...	...	...	...
1908	413,370	1,166,046	854,825	734,331	...	...	...	...
1909	438,264	1,472,423	1,333,535	759,508	4,763	...	...	...
1910	538,496	1,704,981	1,681,324	787,106	112,712	20,550	5,240	...
1911	600,355	1,819,075	1,727,154	806,429	244,700	35,010	74,758	...
1912	706,279	1,840,991	1,791,150	805,700	310,306	285,942	162,158	...
1913	763,634	1,785,548	2,008,529	919,843	347,206	404,687	293,767	...
1914 ¹	502,000	826,000	1,014,000	541,000	273,000	259,000	291,000	...
1915 ¹	"	372,000	409,000	"	"	"	"	...
1916 ¹	"	982,000	881,000	324,000	"	"	"	...
1917 ¹	231,000	980,000	807,000	591,000	9,000	98,000	"	...
1918 ¹	189,000	806,000	683,000	583,000	"	"	"	...
1919 ¹	210,029	52,164	37,282	92,371	10,574	6,243	"	...
1920	402,830	214,003	509,248	218,487	114,669	123,181	7,576	...

Landres Ore-Field.—The Landres ore-field, which extends westwards of the Bonvilliers and Norroy faults, is elliptical in shape, its major axis extending for 12 kilometres, and its minor axis being 6 kilometres long. The thickness of the grey seam, which is the only one workable, compensates greatly for the absence of the others. It varies in thickness from 5 to 9 metres, except in the west, where it falls, at Dommery, to 4 metres, and eventually peters out.

On the southern border of the basin the ferruginous formation comes to a sudden end, both in thickness and iron content. On the northern border there is, on the contrary, no diminution in thickness, but a falling off in the iron content which renders its working useless, while at the same time the calcareous gangue changes to a siliceous gangue. The floor of the seam is from 180 to 240 metres below the surface.

In this lenticular formation may be distinguished, as Mr. Villain points out, two regions, the first, in which the thickness of the seam varies from 5 to 7 metres, and where the ore is gener-

¹ From August 1914 to November 1918 exploited by the Germans, after the Armistice returned to the owners. The same remark applies to the two following tables.

ally greyish green and contains, when dried, 12 per cent. of lime, 6 per cent. of silica, and 35 to 42 per cent. of iron; and the second, where the seam is 6 to 7 metres in thickness, and bears throughout the whole of the north-western portion of the ore-field, an ore containing 31 to 35 per cent. of iron, 17 per cent. of lime, and 6 per cent. of silica. In this second region the ore is often associated with chalky nodules, which are distinguishable from the mass by their lighter colour. These have, when they occur abundantly, to be separated specially, an operation which enriches the residual ore.

In some portions of the grey seam specially rich zones are encountered, such as the black ore to which reference has been made. Again, in certain places in the Pienne and Joudreville concessions, the grey ore changes for part of its thickness into the so-called "chocolate" ore, containing appreciably more than 42 per cent. of iron, low in lime (6 to 7 per cent.), and higher in silica (7 to 8 per cent.). The amount of these special varieties is, however, small.

A characteristic of the ore should be borne in mind. Throughout the Landres region the iron and lime in the ore, as dried at 110° C., is always in the vicinity of 50 per cent., and varies but little from this proportion.

The following table gives the output of the field since 1905:

Year.	Landres.	Pienne.	Amermont.	Joudreville.	Murville.	La Mourière.
1905	15,559	68,605	...	...	...	...
1906	105,437	123,690	...	...	...	...
1907	289,409	252,840	...	...	...	...
1908	419,217	450,629	3,260	2,348	...	...
1909	640,236	664,734	78,156	120,833	4,930	...
1910	786,150	843,645	320,553	359,719	129,315	32,575
1911	851,763	975,996	596,391	562,090	238,935	124,807
1912	955,972	1,090,959	916,129	721,301	323,900	429,918
1913	1,087,900	1,134,184	1,068,191	883,834	422,600	684,083
1914	549,000	533,000	696,000	469,000	315,000	511,000
1915	"	"	"	"	"	"
1916	7,000	"	"	5,000	"	3,000
1917	303,000	"	"	405,000	"	185,000
1918	416,000	"	"	447,000	"	"
1919	41,348	"	"	8,647	"	10,194
1920	243,737	"	"	185,599	"	219,026

During the course of hostilities the Landres mines, such as those at La Mourière, Joudreville, and Landres itself, were worked by the Germans occupying the region under conditions no better than those of the Orne iron-mines. Others, like those of Murville, Pienne, and Amermont, were abandoned, and have hence become flooded. Of these, the Murville mine was not unwatered at the beginning of 1921.

The restoration of the unflooded mines has been a lengthy process, alike owing to the industrial crisis, to the destruction of many works which owned them, and to the scarcity of labourers, who, as will be explained later, were, before the war, mainly Italians, and the great majority of whom have not returned to France.

Tucquegnieux Ore-Field.—The Tucquegnieux ore-field, which forms the third subdivision of the Briey basin, extends to the east of the Bonvillers, Norroy, and Audun-le-Roman faults, and to the mouth of the Avril fault which marks its southern boundary.

Four pits are working, at Sancy, Tucquegnieux, St. Pierremont, and Anderny. They were opened successively in 1904, 1906,

Year.	Sancy.	Tucquegnieux.	St. Pierremont.	Errouville.	Anderny.
1905	...	66,402	...	...	...
1906	5,156	104,513	...	...	...
1907	90,942	288,590	...	...	...
1908	121,832	441,142	...	...	...
1909	296,516	491,000	5,577	...	...
1910	384,644	697,430	104,099	...	2,429
1911	539,718	846,445	277,389	...	83,937
1912	584,363	1,011,634	483,612	...	256,999
1913	688,000	1,113,200	846,153	175,530	480,000
1914	410,000	543,000	548,000	176,000	356,000
1915	"	"	"	"	"
1916	11,000	9,000	"	1,000	3,000
1917	368,000	264,000	"	171,000	185,000
1918	365,000	333,000	"	"	"
1919	"	66,688	"	103,997	5,768
1920	287,173	438,422	188,977	230,891	212,800

1909, and 1910. The grey seam predominates and its thickness reaches 6 to 7 metres. The ore is fairly high in iron, particularly in the environs of Mairy, and has a markedly calcareous gangue.

On the other hand, the brown, black, and green seams have been met with near Audun, although seldom all three together.

They are generally siliceous. Near Anoux, St. Pierremont, and Chevillon the red seam possesses considerable interest, and calcareous iron ores occur near Audun.

Near the Tucquegnieux ore-field there is a zone, rather more north, between the Audun and the Crusnes faults, which corresponds more with the ores of recovered Lorraine. This is of interest inasmuch as, while the grey seam is almost always calcareous and relatively low in iron, the lower siliceous seam is much richer. A pit was sunk in 1912 from which, in 1913, 173,530 tons of ore were extracted, containing 15 to 16 per cent. of silica and 36 to 39 per cent. of iron, from the brown seam.

The table on p. 29 gives the ore production from mines in this region.

This concludes the brief description of the Briey ore-field, which testifies to the predominance of the grey seam, the ores of which are important as regards their iron content and their siliceous gangue.

Methods of Working in the Briey Ore-Field.—Few mining districts have been as rapidly developed as the Briey ore-field or on so large a scale, notwithstanding that numerous difficulties have had to be surmounted.

The grey seam (and the others, when they occur) can only be reached by means of shafts. The drainage difficulties have been considerable, and have, in some instances, necessitated special methods of sinking.

Some shafts as, more particularly, in the case of those first sunk in the Joeuf and Homécourt concessions, have either had definitely or temporarily to be abandoned, the pumping arrangements being insufficient. Some shafts have been sunk by freezing or cementation methods at Auboué, St. Pierremont, and Giraumont, but, generally speaking, it has been found that, by the use of powerful steam or electrical pumps suspended in the shafts, the problem can be satisfactorily dealt with.

The depth of the pits varies in each district. From east to west the seam dips and thus the average depth of pits varies from 65 metres at Joeuf, 73 and 114 at the two Homécourt mines, 90 at Moutiers, 120 at Auboué, 165 at Valleroy, and 207 and 212 at Jarny and Droitaumont.

In the Landres district the Murville pit is 192 metres in depth,

Landres 223, Pienne 220, La Mourière 235, Amermont 225. In the Tucquegnieux basin, St. Pierremont 179, Anderny 203, Sancy 240, and Tucquegnieux 240 metres.

While the sinking of shafts has often presented considerable difficulties owing to the intervention of water-bearing strata, the actual work of mining is little less difficult owing to the water met with in the seams themselves. If, as in certain mines such as Ste. Marie in recovered Lorraine, over 30 cubic metres of water are encountered per minute, and such quantities have not as yet been met with in the Briey shafts, this is only because the latter has been developed much more recently, the workings are relatively much less extensive, and the surface subsidences much less marked. Even before the war, however, over 13 cubic metres of water were met with at Auboué, from 6 to 11 at Landres, and about 6 at Jarny.

The bad methods of working adopted by the Germans during the war, and the heavy blasting operations they indulged in, have very considerably increased the pre-war amounts in which water was encountered, and at Auboué, for instance, 25 cubic metres per minute have to be dealt with. In 1919, in the fifteen iron ore mines of the Briey basin (without counting Murville, Amermont, and Pienne, which were flooded out, even by that time), the maximum duty the pumps had to comply with amounted in the aggregate to $105\frac{1}{2}$ cubic metres per minute, as shown by the mining engineer's official reports. It was thus necessary to equip the mines with powerful pumping stations, capable not only of dealing with the ordinary requirements, but likewise with sudden exceptional inrushes similar to those which occurred occasionally in recovered Lorraine as the result of blasting or of prolonged rains. In some mines underground pumps capable of dealing with 50 cubic metres per minute have been already installed, but it will be understood that this could not be done without entailing heavy expenses.

These plants and this inflow have led to this, that to counteract their influence on the selling price of the ore very large tonnages have to be extracted. Hence the Briey mines are mostly provided with winding plants capable of dealing with some two millions of tons per shaft, at any rate so far as those most recently opened up are concerned.

The working class population of Lorraine is small and recourse has had to be had to foreign labour, particularly Italian, on which, in proportion as production increases with the progressive opening up of mines, it will be increasingly necessary to depend. The sinking of shafts in what had been wholly an agricultural region necessitated the creation of large workmen's colonies in the neighbourhood of the mines. Thus whereas the mining companies in Nancy and Longwy housed, before the war, only 5·2 and 28·4 per cent. of their workmen, the proportion in the Briey region had reached 62·8 per cent. Thus the iron ore mines of Briey have resulted in large capital sums being locked up in this way. With the pre-war value of money it was usually reckoned that to open a mine in this region required a capital outlay of 10 to 15 millions of francs. With the present value of money at least three times as much would be required.

Longwy Ore-Field.—The Longwy ore-field forms a strip along the frontier between the department and the Grand Duchy of Luxemburg. It comprises seams readily worked by surface stripping or even by opencast methods, as is the case at Hussigny. In this region, as a matter of fact, the outcrop of the iron-bearing formation is close at hand, and the deep valleys which intersect it allow of the seams being, generally speaking, worked without shaft-sinking.

The seams are, for the most part, freely siliceous. The chalky ironstone, which is also frequently found throughout the district, is naturally of a different nature, chemically speaking. The percentage of iron, which in the latter varies between 20 and 28, amounts in the siliceous beds to 32 to 40 per cent., with 13 to 20 per cent. of silica and 3 to 7 per cent. of lime.

In the Longwy basin the chalky ironstone, and the red, yellow, grey, black, and green seams, are workable, but these horizons rarely occur simultaneously, and, more particularly west of the Longlaville fault, only the grey seam is met with. Between the Godbrange and Crusnes faults, however, the red seam is met with under conditions of great uniformity, together with variable occurrences of the grey, black, and green formations. Between the Longlaville and Godbrange faults the chalky ironstone and the yellow and red seams are encountered.

The thickness of the seams varies, generally speaking, from

1 to 4 metres, and may even reach 7 metres, as, for instance, in the Saulnes district, where the red seam and the chalky ironstone are in contact without any parting.

The production since 1907 has been as follows :

	Tons.		Tons.
1907 . .	3,212,000	1914 . .	1,465,000
1908 . .	2,677,000	1915 . .	239,000
1909 . .	2,641,000	1916 . .	417,000
1910 . .	2,862,000	1917 . .	660,000
1911 . .	2,839,000	1918 . .	655,000
1912 . .	2,943,000	1919 . .	189,853
1913 . .	2,958,000	1920 . .	714,610

The ore-field was entirely occupied by the enemy from August 1914 to the Armistice. The mines were found subsequently to be in a very bad condition, particularly those which had been carelessly worked by the Germans.

The iron ore of the district was chiefly consumed in France, but in 1913 a fair tonnage was sent abroad, amounting altogether to 504,000 tons, of which 175,000 tons were sent to Belgium and 58,000 to Luxemburg.

Crusnes Ore-Field.—This extends from the south of the Longwy ore-field to the northern boundary of the Landres ore-field, being, as a matter of fact, neither more nor less than a prolongation of the Longwy field, from which it only differs by having to be worked by pits, and by its discovery being due to borings made within recent years. It is indeed the newest region of the whole Lorraine ore-field, as the concessions—Grand-Rimont, Audun-le-Roman, Mercy-le-Haut, and Bazailles—only date from between 1912 and 1914.

So far as has been ascertained by means of boreholes the ore is, generally speaking, siliceous, and the grey seam, which is widely distributed, has a thickness varying from 2 to 5 metres. The ore contains 30 to 36 per cent. of iron and 16 to 20 per cent. of silica. The lower beds are, at certain points, workable, and contain 30 to 38 per cent. of iron and 12 to 20 per cent. of silica. Of the upper beds, the red seam, which is met with here and there, is unworkable. To win the ore necessitates the sinking of shafts to a depth of 100 to 150 metres.

ORE-FIELDS OF RECOVERED LORRAINE (MOSELLE).

The ferruginous formation outcrops in recovered Lorraine, that is, in the department of the Moselle, all along the slopes of the western banks of the river, and is contiguous with the formations already described and met with on the other side of the former frontier, in the department of Meurthe and Moselle, that is, so far as relates to the zone beyond the Nancy ore-field, the latter being an entirely isolated ore-field in the south.

The structure being thus fundamentally the same, even the same faults, known by other names, occur. Thus, the Audun-le-Tiche ore-field corresponds with the Longwy ore-field west of the Crusnes fault, here known as the Audun-le-Tiche fault. The strip described as the Errouville concession extends, in the east, as that between the Audun-le-Tiche and the Ottange faults. It is known as the Aumetz ore-field.

Between the Ottange fault, the prolongation of the Audun-le-Roman fault, and the Neuchef or Hayange fault (a prolongation of the Avril fault) extends the Fontoy, or Fentsch ore-field, so called after the name of the river which traverses it : this ore-field is a continuation of the Tucquegnieux ore-field. To the south of the Hayange fault extends the Orne ore-field corresponding with that of the same name in Meurthe-et-Moselle, while, finally, more to the south, occurs a further ore-field, Ars-Novéant, corresponding with areas in Meurthe and Moselle, where, however, no ores occur.

Throughout these regions the same series of beds occur as already described in regard to Longwy and Briey, but often under different names. They seldom all occur simultaneously, two only predominating, the grey seam and the black. The iron content is generally much lower than in the neighbouring regions in Meurthe and Moselle ; percentages of 33 to 34 are seldom exceeded. Thus with the exception of certain localities such as Esch, Audun-le-Tiche, and Aumetz, where the ore reaches 35 to 40 per cent. of iron, they are of little interest from the export trade point of view. Although the black seam likewise offers some rare instances of greater iron content the iron ores of recovered Lorraine possess little interest except for the blast-furnace

plants in their immediate neighbourhood, such as Hagondange, Rombas, Knutange, Hayange, Moyeuivre, Uckange, and Ottange. They are equally well situated in regard to the Saar region, which is not far removed by rail, and if, prior to the war, large tonnages of these ores were sent for use in Westphalian blast-furnaces, the reason was rather because of the specially advantageous tariffs which the German railways charged for the transport of these ores. At present, now that conditions have greatly changed, and that from the point of view of the distances to be travelled on the German railways there is little difference between the ores of either department, the much richer Briey ores will tend more and more to supplant the Moselle ores in German trade

RESOURCES OF THE FRENCH LORRAINE DEPOSITS.

If all the ore-fields be taken into account it may be estimated that the ore resources of the Nancy field amount to 200 million tons ; those of Longwy to 275 millions ; those of Briey to 2000 millions, and those of Crusnes to 500 millions. To this estimate must be added the 1750 million tons attributed by Mr. Kohlmann in 1913 to the recovered Lorraine, which gives nearly 5000 millions as the total iron ore reserves of French Lorraine. Earlier estimates by M. Leprince Ringuet and by M. Langrogne, for the pre-war and news portions of French Lorraine, agree very closely with this estimate, and show how vastly important these deposits are.

The most important, from the point of view of an export trade with Great Britain, are those of Briey. The Longwy and Nancy regions, which possess ores rich enough, do not possess reserves which would encourage an external trade, and the works would find it more to their interest to retain for their own use the relatively small tonnages still available. The ores of recovered Lorraine are obviously lower in grade, and not worth the long journeys required before they could be delivered to British centres. From this point of view it is only the Briey ores which need more detailed discussion, and at the outset it will be well to draw attention to a point which, if not taken seriously into account, might lead to serious misconceptions. The ores are not of invariably uniform quality, even from the same mine or from

the same levels in one and the same seam. The seams are indeed to be regarded as consisting of a series of beds of variable quality, some richer and less limey, others leaner and more limey. The rich beds are often lenticular, and it is an admixture of the ores from different beds at the same level that yields the average figures given above for the different districts. In order, therefore, to obtain accurate analytical results it is necessary to sample large tonnages and to take the samples with the greatest care. The best and most accurate method is to take the results at the blast-furnaces themselves, or the mean results of the ore outputs extending over several days, which give figures which run fairly constant in respect of any given mine.

In order to obtain, under the most favourable conditions, a uniform average composition, many of the mines of Briey have built huge bunkers into which are delivered throughout the day the ores derived from various working places, and where what may be termed automatic mixing takes place, with the result that the ores as delivered from the bunkers yield extremely uniform results. The bunkers at Landres and at Sancy, for example, have a capacity respectively of 16,000 and 12,000 tons. Another factor which contributes to the uniformity of the outputs of any given mine is the degree to which the workings have extended, so that the bunkers receive ore from widely different working places in the same mine. It is thus easier to ascertain the average composition of the output of a mine which has been well opened out and is being fully worked, than that of a new mine which has just begun working. In these circumstances it may be said, broadly, that the Briey ores of the grey seam, the only one hitherto worked, yield, on a sample dried at 110° C., 36 to 42 per cent. of iron, 9 to 14 per cent. of lime, and 4 to 7 per cent. of silica, the average moisture of the undried ore being 8 to 11 per cent.

No mention has been made hitherto of the phosphorus content. The ratio of phosphorus to iron varies within exceedingly narrow limits, and corresponds exactly with that required in the manufacture of basic pig iron. So uniform is this ratio that it is not customary to make routine estimations of the phosphorus, as is necessary, for instance, in the case of Swedish ore. It should also be noted that the sum of the iron and the

lime content of the Briey ore amounts very regularly to 50 per cent.

These ores have another characteristic which is of great interest. They require less coke, in blast-furnace working, than their low iron content would lead it to be assumed. A mixture of the Briey ores with the ordinary siliceous ores of Lorraine leads, in practice, to a consumption of coke varying from 950 to 1050 kilogrammes per ton of pig iron. This easy reducibility is a property of no mean value.

THE IRON ORES OF NORMANDY, ANJOU, AND BRITTANY.

The iron ores of Normandy, Anjou, Maine, and Brittany are, from many points of view, and particularly from their geographical situation, the most suitable of all the French deposits for British ironworks. All the mines now, or in the future, to be worked are in close proximity with the sea. Those of Segré, in the Anjou ore-field, the farthest from ports of embarkation, are only 85 and 135 kilometres distant by rail from Nantes and St. Nazaire respectively, while the Ferrière and Halouze mines, the farthest south of the Normandy mines actually in operation, are within 75 and 80 kilometres of Caen.

The freight question is likewise favourable. The whole of Western France normally looks for its coal requirements to foreign countries and, because of its proximity therewith, more especially to Great Britain, while the colliers can count on return cargoes of iron ore, a factor which must exert its influence on the freights each way. Taking the pre-war year 1912, when things were normal, and conditions of the kind to which all look forward in the future, the imports of coal at the three ports of Nantes, St. Nazaire, and Caen alone amounted to 2,289,797 tons, and those of coke to 19,686 tons. Out of this total of 2,309,483 tons of fuel, no less than 1,976,536 came from Great Britain. Yet, in this year the exports of iron ore from Caen to Great Britain amounted only to 93,604 tons, while those from Nantes and St. Nazaire together did not equal this amount.

Before the war a large number of important German companies had acquired considerable interests in the iron ore mines of Western France, and a heavy trade with Westphalia

had commenced. At Caen, more especially, the exports to Germany, which in 1908 amounted to 131,193 tons, had risen by 1913 to 342,281, whereas for these two years the exports to Great Britain had only risen from 81,999 to 144,409 tons. Even at this time, however, a tendency considerably to increase her imports from Normandy was apparent, and now that, in accordance with the peace treaty, the ore mines and interests which Germany possessed in Normandy, Anjou, and Brittany have reverted, in liquidation of French interests sequestered in Germany, to French hands, the ore trade with England should increase rapidly with the coming years.

The brief description of the ore deposits of these provinces which follows will serve to show how greatly their physical and chemical properties should commend them to British blast-furnace owners as a source of supply.

Normandy.—The Normandy deposits spread over the three departments of Calvados, Manche, and Orne. They are in point of importance the second largest deposits in France, notwithstanding that, according to the 1912 statistics, they contributed, as compared with Meurthe and Moselle, so small a proportion of the total output.

In 1920, the last year for which provisional statistics have appeared, the proportion has fallen to 3.55 per cent. This decrease is due to the reopening of the French mines in recovered Lorraine; the decrease is even less than might have been expected, owing to the destruction of numerous works and mines in the east of France.

Whatever the statistics may portend, the production of ore from the Normandy mines had appreciably increased during the years which immediately preceded the war, and the 1913 output of 831,637 tons would have justified the hope that in 1914 extractions would have reached a million tons. Great developments were in progress at the Soumont mines, and particularly at St. André and at Barbery, and but for the war the Normandy deposits might well have amounted to several millions of tons annually.

A considerable proportion of this output would have been employed at works in the North of France; Halouze and La Ferrière are mines belonging to the Aciéries de France et de

Denain-Anzin, and the Isbergues and Denain works of the company would have taken the largest proportion of their output. The Forges et Aciéries du Nord et de l'Est had large interests in the Larchamp mine and would have mixed the ores from this mine with those from their Pienne concession in Meurthe-et-Moselle, thus securing a particularly satisfactory burden for their blast-furnaces. These three mines, Halouze, La Ferrière, and Larchamp, all situated on the main syncline of Ferrière, had in 1913 produced 373,000 tons of ore, that is, 45 per cent. of the whole Normandy production. New works in Pont-à-Vendin and at Dunkerque were similarly to have derived a large proportion of their ore requirements from Normandy.

In addition to the foregoing, blast-furnaces in the course of construction in Calvados, in the immediate neighbourhood of Caen, to be provided with steelworks and rolling-mills, were to draw their supplies from the Soumont mines, and having associated interests with Westphalian works were to exchange ore for coke with the latter, thus accomplishing a purpose towards which British ironmasters ought now to address themselves. Other concessions in which Germans held the great bulk of the shares, or in which, through the intervention of Dutch shareholders, they possessed large interests, were equipped with plant destined to increase their productive capacity and develop an extensive trade with their shareholder-customers.

Since the war the situation has greatly changed. The northern works, such as Denain, Isbergues, Valenciennes, and Pont-à-Vendin, have been completely destroyed by the Germans, or so vitally injured that it will take many years to restore them. This is one of the reasons for the notable decrease in the iron ore production of Normandy. The Caen works, taken over by a company which has eliminated the German element, cannot develop to the extent wished for. Hence the Normandy mines must look for their own development to the export trade with which they can easily cope, while meeting all demands likely to be made upon them for home consumption.

The ores are of sedimentary origin, and occur in beds of the Silurian period, or, more correctly speaking, in trilobitic schists of the Ordovician age. The ores usually outcrop in the synclinal parallels running, generally speaking, North 115° East, of which

four have been recognised, buttressed on the west by eruptive and pre-Cambrian rocks, which lie in an easterly direction beneath Jurassic rocks, the thickness of which increases in proportion to their distance from the outcrops.

The location of the deposits has hence been an easy matter in the outcrop areas, as by small surface workings it has been possible to tap the ore beds. In the east, however, the overlying Jurassic formations have necessitated deep borings, and it has only been in quite recent years that the prolongation of the beds east of May has been established for any considerable distances. This has, since the beginning of 1921, led to a fresh series of concessions being granted by the Government, the areas so conceded being nearly as extensive as the whole of the older concessions made between 1875 and 1914.

In each synclinal one or more beds occur. Generally speaking, in the northern portion of the field, which comprises the synclinals at May, Urville, Falaise, and La Ferrière, there is only found one mineralised zone, occupying a uniform position in the trilobitic schists, either at their contact with the Armorican sandstone, or about 40 metres above this contact.

In other synclinals farther south, between Alençon and Bagnoles, five more or less important ferruginous horizons are encountered, spread more or less uniformly along the upper surfaces of the schists. Thus, one is found at the contact with what is termed the May sandstone, at Bagnoles, and a similar horizon occurs in the Sees ore-field, where, as the result of long-continued investigations, a large concession has recently been granted.

The thickness and general aspect of any one bed are fairly uniform in any one syncline, or rather along the same side of a syncline, as there may be considerable variation as between its two limbs. Between one syncline and another there may be considerable difference in appearance as though, according to Mr. Barrois, the original deposit corresponding with the limbs of any one syncline or of different synclines, had originally been spread over very wide surfaces, and these had been thrown together in their present form as the result of exceedingly powerful geological forces of compression and thrust, which have brought into contact regions of sedimentation naturally differing owing to their distance from each other.

The dip is always considerable, varying from 30° to 85° , and except in the St. Rémy region the bottom of the synclinal has not been reached. Some observers, such as Mr. Cayeux, contend that the convergent slopes of a given synclinal only meet at many thousands of metres below the surface. If this be so, the ore reserves of the Normandy ore-field must be enormous.

The ore occurs either as an oolitic carbonate or a hæmatite. Both may exist simultaneously, as its hæmatite always passes into carbonate at a greater or less depth. Normandy hæmatites are at present chiefly mined at St. Rémy, St. André, and May.

The St. Rémy ores are the richest of all the Normandy ores, and contain 52 to 55 per cent. of iron, 10 to 12 per cent. of silica, 3 per cent. of alumina, 2.5 per cent. of lime and magnesia, 0.6 to 0.7 per cent. of phosphorus, and 3 per cent. of water. At St. André and May the iron percentage is lower, being between 46 and 51, with 14 to 16 per cent. of silica.

The other concessions contain chiefly or entirely carbonate ores which have to be calcined to avoid the carriage of waste matter. Only 12 to 15 kilogrammes of fuel per ton of ore is required for calcining them, and the yield can reach from 75 to 79 per cent. at Halouze, La Ferrière, and Larchamp.

On their withdrawal from the kilns the ores from these three mines contain :

	Iron per Cent.	Silica per Cent.
Halouze	48 to 49	14 to 16
La Ferrière	47 to 49	13 to 15
Larchamp	48 to 49	14 to 15

The proportion of alumina varies from 4 to 7 per cent. and the lime and magnesia from 3.5 to 4.5. The phosphorus remains between 0.6 and 0.7 per cent. These calcined carbonates are therefore relatively rich, and the three mines in question are just those from which exportation would be the easier.

Soumont ores only yield 45.9 per cent. of iron after calcining, the silica being higher than in the ores just described. The ores of Mortain, Bourberouge, and Jurques are very similar to those of Soumont.

It will be seen that while the ores are somewhat siliceous, they are, generally speaking, high in iron. Their composition shows that they are suitable not only for making basic pig iron

but also for mixing, while without any fluxes they can make phosphoric foundry pig containing 1·2 to 1·3 per cent. of phosphorus, as well as pig iron suitable for open-hearth furnace working.

The carbonates are usually porous when calcined, as is shown by their weight per cubic metre. This varies, after calcination, from 1600 to 1650 kilogrammes, and thus presents a distinct advantage when they are smelted.

Occurrence and Working.—Four principal regions may be distinguished, each corresponding with a particular syncline: May, Urville, Falaise, and La Ferrière. The most northerly comprises the concessions of May, St. André, Bully, and Maltot, which were granted before the war. Only two of these are being worked. At May the beds have a dip of 45° and a thickness varying from 4 to 6 metres, but of which only a thickness of 2·5 metres is being actually worked, the remainder being too high in silica. The sinkings carried out by the Société des Mines et Produits Chimiques reach a depth of over 100 metres below the surface and extend underground for over 4 kilometres. A large shaft at Lorguichon, near to the mineral railway connecting the Soumont mine with Caen, has been sunk to a depth of 150 metres and will allow of an annual production of 150,000 tons of ore. This ore is a hæmatite containing 46 to 47 per cent. of iron. In 1913 production had reached 100,189 tons to fall, owing to the war, to 45,256 tons in 1919. In 1920 it had increased to 62,051 tons.

At St. André an almost vertical bed is worked to a depth of nearly 100 metres, and the ore is got from a bed of hæmatite 2·5 metres thick, overlaid by a bed of carbonate not yet being worked. The outputs in 1913, 1919, and 1920 respectively were 89,225, 60,956, and 75,567 tons. The Bully and Maltot concessions have hitherto only been explored by boreholes.

It is along the May syncline that investigations eastward have been pursued to ascertain whether the workable beds of May and St. André extend. The results have been of sufficient interest to warrant the Government granting, since 1921, a series of concessions extending as far as the railway from Argentan to Mezidon and further. These concessions at Condé-sur-Ifs, Fieville, Garcelles, Ouézy, Ouville, and St. Pierre-sur-Dives cover a greater area than all the others in Calvados put together.

The second syncline, sometimes known as La Brèche du Diable, but more commonly as Urville, comprises six older concessions—Soumont, Perrières, Barbéry, Estrées, Gouvix, and Urville. Investigations made, in this instance, westward, have led to the prolongation of the syncline being established as far as its outcrop, and have led, since the commencement of the year, to the granting of the Cinglais concession.

Of all the concessions of this second basin the most important in every respect is that of Soumont, which supplies the Caen blast-furnaces of the Société Normande de Métallurgie, with which they are linked up by a private railway. Here there occurs a seam of carbonated ore having a dip of 30° , which appears, from boreholes sunk to depths of 400 metres, to get less steep as it becomes deeper. So far the seam has been proved for a depth of 200 metres by slopes and roads which have established its continuity and constancy. The ore gives, on calcination, 45.9 per cent. of iron, and roads have been driven for several kilometres. Down to depths of 60 metres hæmatite is found, but below these depths it disappears completely.

In 1913 the mine produced 71,637 tons of ore, of which 9000 tons were imported into Germany and the rest put into stock. Since that date the work done by the new company owning the Caen furnaces (Société Normande de Métallurgie) has been directed to supplying adequate quantities of ore for the consumption of the blast-furnaces and to making calcining tests, which have yielded excellent results. In 1919 the output of carbonate ore amounted to 40,401, of which 24,042 went into stock and 16,358 was passed through the kilns. By December the stocks had risen to 219,602 tons of raw ore and 52,223 tons of calcined ore. These stocks were heavily drawn upon during 1920 for consumption at the works. During 1920 Soumont produced 4339 tons of hæmatite and 65,322 tons of calcined carbonate.

The Barbéry concession, in which the German Gutehoffnungshütte held the interest, was naturally sequestrated during the war, and has since been completely idle. In 1913 the production was 16,624 tons of calcined ore from a bed in which only a thickness of 2.5 to 3 metres was worked, to avoid getting a too siliceous ore. Arrangements had been made for the rapid development of this mine for an output of 300,000 tons, which

shows the importance attached by German metallurgists to the Normandy deposits. Soumont, which was also to supply part of the ore needed at the Thyssen works in Westphalia, was in 1914 being prepared for an output of 500,000 to 600,000 tons annually, beginning with 1915. The war stopped this development, but the plant is capable, whenever required, of realising such outputs.

Of the other concessions on this syncline, only the Gouvix mine has been restarted by the Société des Forges et Aciéries de Firminy, for the purpose of getting ready to supply the Dunes works near Dunkerque. The ore is a carbonate, and calcining kilns have been installed. Extraction has only been of a preparatory nature, and the tonnage has hence been small.

The third Normandy syncline, that of Falaise, is the best known, as it contains the St. Rémy concession, the oldest (having been granted in September 1875) and the richest. A bed of hæmatite 2·5 metres, of very uniform quality overlaid by a thickness of about 1 metre of carbonate ore, is worked. The carbonate ore has a purplish colour and was not formerly worked, although for a few years it has been exploited. The hæmatite contains 51 to 55 per cent. of iron and the raw carbonate 41 to 42 per cent., with 12·9 per cent. of silica. The bed is only worked to slight depths—33 metres—below the surface.

Production, which in 1912 reached 106,852 tons, fell in 1913, as the result of a long strike, to 77,620 tons. In 1920 the output was 78,713 tons, of which 43,218 tons were hæmatite and 35,595 tons were carbonate.

The remaining concessions on this synclinal, at Ondefontaine, Jurques, and Montpinçon, produce only carbonate of much poorer quality, and with the exception of Jurques, which has been worked by the Société Française des Mines de Fer, have been little developed. At Jurques there appear to be three beds, two of which are workable, but of which only one is at present being worked. It has a thickness of 1·80 metre and a dip of 55°. The investigations quite recently made at Montpinçon have led to the recognition of only one seam, much faulted and probably unworkable. The description of these three synclinals completes the account of the Normandy deposits occurring in the department of Calvados.

The fourth syncline spreads over the departments of Orne and La Manche, and covers two widely differing regions: the eastern in Orne, with the Mont-en-Gérôme, La Ferrière, Halouze, and Larchamp concessions, and the western, containing the Mortain and Bourberouge concessions.

Larchamp, Halouze, and La Ferrière are at the present time the three most important mines in Normandy and, with the exception of St. Rémy, the richest.

The first-named produces only carbonate. Throughout 1919 it was only working part time, and whereas in 1913 its output was 89,896 tons of calcined ore, in 1920 it only produced 18,275 tons of raw ore, and 14,588 of calcined ore. The seam has a thickness of 5 to 8 metres, with numerous changes of dip and strike, creating difficulties in working. One shaft is at work, and the ores are transported by an aerial ropeway to the station at Chatelier, 7 kilometres away, on the line from Domfront to Flers. Twelve calcining kilns, with forced draught, have been installed at the mines.

The Halouze concession, along the immediate prolongation of the latter, has a somewhat narrower seam, 5 to $7\frac{1}{2}$ metres in thickness. It is worked by two shafts, each 180 metres deep, and by an incline. Actual working is confined to depths not exceeding 130 metres, but provision has been made for extraction at greater depths. There are eight calcining kilns, and a railway 8 kilometres in length connecting the mine with the station at Chatelier. The output in 1913 was 152,656 tons of ore. In 1920 only 44,559 tons of raw ore were produced, and 40,678 tons of calcined ore were despatched. In some places the concession yields a hæmatised ore, but in small amounts only as compared with the carbonate ore. The mine belongs to the Compagnie des Aciéries de France.

At La Ferrière, which belongs to the Denain Anzin Company, the seam is the prolongation of that encountered at Larchamp and Halouze, and has a dip of between 35° and 40° south, which becomes steeper northwards before reaching Halouze. Eight kilns are installed for calcining the carbonate ore, and the mine is connected by rail with the St. Bomer station on the Flers-Domfront line. Most of the ore of this concession was, before the war, used at the works of the proprietors, but these having

been destroyed by the Germans the output has been greatly reduced and only the requirements of outside customers have been catered for. While, in 1913, 121,650 tons of calcined ore were despatched from the mine, the 1920 output was only 32,500, while the kilns calcined 50,100 tons, the difference being taken out of stock.

Of the other concessions on the La Ferrière syncline, the Mont-en-Gérôme mine is not as yet being worked, only trial borings to ascertain the existence of the seam, its thickness and quality, having been carried out. According to the information yielded by these bores, the seam is less important than those just described. At Bourberouge there is a workable seam of 2·5 metres thick with an average dip of 39°, and at Mortain the thickness reaches 6·5 metres, and the minimum dip is 54°, which becomes steeper as the depth increases. Both these mines, which belong to the Société Française des Mines de Fer, were before the war worked for the export trade. They are connected by rail respectively Bourberouge with the Domfront to Avranches line, and Mortain with the Vire to Mortain line. Kilns were installed, but by 1913 production had only just begun, and the output was 34,553 tons of calcined ore at Bourberouge and 6833 tons at Mortain. The former mine became flooded during the war up to its adit level; at Mortain the same thing occurred to the lower levels.

It is exceedingly difficult at present to estimate the resources of the Normandy deposits, as not only are large areas incompletely known, but those which are worked have been worked on too small a scale and at depths too shallow to warrant generalisations on the scanty data available. All that can be said is that the deposits are rich enough to justify intensive production running into several millions of tons per annum. Indeed, taking into consideration only the known deposits, and basing the estimate on an average possible depth of 400 metres, there would be 220 millions of tons, while if, as some of the seams appear to indicate, the synclinal apex is 1000 metres or more below the surface, the ore reserves might be very much greater, even without taking into account any of the newly made concessions. In any case they afford, both by their proximity and their richness, a most important source of supply for British ironworks.

This note on the Normandy ores would be incomplete without mention of an iron mine differing in every geological and mineralogical feature from the foregoing mines. It is situated at Diélette, in the department of La Manche, where certain almost vertical seams occur, outcropping below the sea and plainly discernible at low tide.

This concession has been made the object of submarine exploration, undertaken a few years before the war by the Société des Mines et Carrières de Flamanville, a company behind which lurked the German owner Thyssen. Considerable plant was installed, and the lower workings were reached by shafts, the deepest of which was 150 metres. One of the seams was 8 metres thick and had a dip of 70° to 80° . Drainage pumps with a duty of 18 cubic metres per minute were installed in the lowest level and protected from unexpected inrushes by heavy ties. A marine loading station had been installed by means of a floating caisson. The plant was sequestered during the war, and has since been completely destroyed by violent storms. The caisson forming the loading stage for the ores was carried away in 1915, and the intervening pylons carrying the aerial ropeway from the islet to the beach suffered considerably. It would appear as if the whole of the work will require to be begun afresh.

The ore is a kind of magnetite, carrying 50 to 52 per cent. of iron, and very hard. 20,000 tons were produced in 1913.

ANJOU AND BRITTANY.

If it be difficult to give definite estimates of the amount of the Normandy deposits, it is still more premature to attempt to do so in regard to those of Anjou and Brittany.

From a geological point of view these deposits considerably resemble the former. There is the same series of synclinals extending from the south-east to the north-west, and containing a number of seams of varying thicknesses and intercalated in Silurian and sometimes in Cambrian formations.

The regularity of the seams is much more variable than in the Normandy deposits, and it is probable that working will be confined to a few of the richest points in the metalliferous belt. According to Mr. Stouvenot, who in February 1920 published in the *Annales des Mines* a highly detailed account of these

deposits, such points may be found, to the number of twenty or so, with an average extension of some 1500 metres in length, 500 metres in width, and with an average thickness of 3·50 metres.

The ore is generally a hæmatite or a magnetite, with an average density of 4, from which it will be seen that, with a marginal safety coefficient of 66 per cent., each of these points might contain 7,000,000 tons of ore, or 140 million tons in all.

The number of fields may, however, be considerably greater, and investigations which have been carried out since 1912 all over the areas in Maine-et-Loire, Ile-et-Vilaine, and Loire-Inférieure may lead to far higher estimates. The present note has no further object than to point out that very extensive deposits of iron ore may be met with in the Anjou-Brittany region.

Iron ore has been known, mined, and worked in Brittany, Maine, and Anjou since very remote periods, as shown by the slag heaps from Catalan forges encountered at numberless localities, and the large number of small blast-furnaces known to have been operating in the eighteenth century.

The superficial deposits were chiefly worked, although deeper seams were also worked, and these old workings have served as starting points for modern investigations. From 1874 to 1910 nine concessions were granted—six in the region of Segré, consisting of Champigné, La Jaille-Yvon, La Ferrière, Oudon, Le Bois, and Les Aulnais, and three others near Angers, St. Barthélemy, Le Pavillon, and l'Ombrée. The development of the Normandy deposits in pre-war years attracted much attention to the Anjou-Brittany deposits, and many investigations were carried out towards the west. These led to the discovery of mineralised belts not yet conceded except for one at Teillay, granted in 1920, in the neighbourhood of the celebrated iron ore quarries of Rouge.

The nine concessions near Angers and Segré have developed rapidly since 1907, and rose from 3418 tons in 1907 to 86,349 tons in 1911, and 130,193 tons in 1913. Some of the ore used to be exported to England and some to Germany, but a fair proportion used at the Trignac works of the Société de la Basse-Loire, near St. Nazaire, which were largely dependent upon these supplies. A subsidiary company of the Société de la Basse-Loire owned the four concessions at Oudon, La Ferrière, Le Bois, and Les

Aulnais, which, in 1913, produced a total of 101,466 tons. The rest of the Anjou output came from the only other concession worked, that at Pavillon, near Angers.

The ore of these concessions is oolitic hæmatite and magnetite, either commingled or separate. Its colour ranges from light grey to reddish yellow, and the iron content, which sometimes reaches 61 per cent., is usually between 48 to 52 per cent. Sometimes very rich places are found, with beds 1 metre thick, giving from 64 to 66 per cent. of iron, with only 4 to 6 per cent. of silica, but such finds are infrequent.

The ore is high in silica (12 to 20 per cent.) and low in lime (1 per cent.). It contains from 2 to 4 per cent. of alumina and 0·6 to 0·7 per cent. of phosphorus.

In order to furnish more complete details in regard to the concessions on what is known as the Segré synclinal, the most important may be taken as an example. Three formations, or ferruginous beds, are recognised; the first towards the summit of what is known as the Armorican sandstone, the second some 40 metres along the wall, and the third 80 metres distance from the second. Only the first two are worked, and these only in part along areas of 300 to 2000 metres, separated from one another by areas which are either too siliceous or too much faulted. The seams are almost vertical; they have a dip of about 70° north along the southern flank of the synclinal.

If we take in succession each of these concessions going from east to west (concessions which are traversed by a railway line from Angers to Segré and Chateaubriant), we first encounter the Oudon concession, where the first seam, which yields 1·20 metre of ore, and the roof of the second seam, the thickness of which varies from 4 to 5 metres (both seams having a magnetite base, yielding on an average 48 to 50 per cent. of iron and 15 to 17 per cent. of silica), are worked by an inclined tunnel to a depth of 68 to 100 metres.

In the Bois and Aulnais concessions the first seam, with a thickness of $1\frac{1}{2}$ to 2 metres, is worked by shafts, as well as the roof of the second, with a thickness of 1 to 1·2 metres, at depths of 40 to 80 metres at Bois and 40, 80, 120, 160, and 200 metres at Aulnais. The two concessions are, moreover, connected by an underground road at a depth of 200 metres.

The iron ore, which continues to have a magnetic base, contains 50 per cent. of iron and 14 per cent. of silica. Lastly, in the Ombrée concession, which is the farthest west, the three previous seams are likewise encountered, but have only been worked at shallow depths. The first and second seams are each from 2 to 3 metres thick, the third is 5 to 6 metres, with several workable beds. A wide shaft is being sunk, the intention being eventually to carry it to a depth of 300 metres. This is on the same Segré synclinal, but over 30 kilometres from the western boundary of Ombrée, where the new Teillay concession is situated.

Another syncline, farther north, comprises the concessions of Champagne, Jaille-Yvon, and La Ferrière. In the two former only exploratory borings have been made, showing the existence of numerous beds, but rather scattered. At one point in the Jaille-Yvon concession a more regular iron-bearing formation is met with, 1.6 to 1.7 metres thick, with a southerly dip of 85° , and containing two seams of magnetite aggregating 1.50 metre thick.

In the La Ferrière concession working has ceased since the war. Two iron-bearing formations, 3.5 to 5 metres and 3 metres thick respectively, about 40 metres apart, and with a dip of 45° , have been found. The Charmont shaft serves the former to a depth of 80 metres, and the ore is got from two beds separated by a bed of quartz. It contains 48 per cent. of iron and 18 per cent. of silica.

South of the Segré syncline and in the vicinity of Angers, in the Angers-Malestroit syncline, four iron-bearing seams occur in a 40-metre belt of quartzose sand and schist, thought to be Ordovician. The beds are almost vertical, and sometimes contorted backwards. Each formation consists of a number of thin veins of ore separated by sterile layers of schist and sandstone, and only yielding 50 centimetres of high grade ore, either magnetic or carbonate, oxidised, in the latter case, at its surface. The formation is very irregular, contorted, and broken. The deposits have not been practically worked except at Pavillon, where from 1910 to 1914 it was worked for about 800 metres to a depth of 70 metres. Working was confined to the almost vertical middle seams. The ore contained 52 per cent. of iron and 12 per cent. of silica.

Exploratory borings in the west, as far as Morbihan, have led to only one concession being made, at Teillay. They have nevertheless established the existence of very similar deposits with the same numerous, variable, and irregular beds, containing occasionally zones where very rich ores occur, of the same types as the foregoing.

Besides these depth deposits there are numerous surface deposits met with in the departments of Loire-Inférieure, Morbihan, Ille-et-Vilaine, and even in La Vendée. These surface deposits are probably the outcrops, or the migrated outcrops of adjacent beds. The most important of these open mines is that of Rouge, north of Chateaubriant, where an ore containing 50 per cent. of iron, 15 to 18 per cent. of silica, and 1 to 4 per cent. of alumina is found. The total output of these open mines grew very considerably during the years just preceding the war, and one-third of it was exported to England. The output in 1913 was 311,500 tons.

In 1912 the ports of St. Nazaire and Nantes, which handled practically the whole of the export of iron ores from Anjou and Brittany to foreign countries, loaded 135,423 and 138,151 tons respectively, Great Britain having had approximately 94,000 tons of the latter amount.

During the progress of hostilities and since the war, the production of the Anjou-Brittany ore-field diminished considerably; whereas in 1914 the output was 296,498 tons as against 399,926 tons in 1913, it fell to 17,436 tons in 1915, and rose only to 90,633, 82,397, and 89,958 in 1916, 1917, and 1918 respectively. In 1919 only 52,211 tons were produced, but in 1920 the amount rose to 119,984, thus showing a considerable recovery notwithstanding that exports had not yet recommenced on a large scale, and that the works in the lower Loire, at Trignac, were practically the only users of the ore.

Taken in the aggregate, the Anjou-Brittany ore-field could, with the appliances with which it is already provided, yield 1 to 2 millions of tons of ore annually, of which two-thirds could be exported, the ore being high in iron and perhaps somewhat siliceous, but being, on the other hand, low in phosphorus. The favourable situation of the deposits in respect to the ports of embarkation, and in particular in respect of large coal-exporting

ports, should serve rapidly to develop trade with Great Britain simultaneously with the exportation of these ores to fresh regions.

CONCLUSIONS.

The foregoing affords a brief description of the two greatest iron ore deposits of France, those in the east and those in the west, from which iron ore importing countries can derive their supplies. Both have been, in different ways, seriously affected by the war, and the falling off in their export trade, as compared with 1914, might lead to the supposition that their world-value had diminished.

This is in no way the case. If the exports to Germany have fallen off considerably it is due largely to the fact that the word has gone forth, and that for the time being German ironworks prefer to purchase Swedish ore, although it is much dearer, in order that, at a later date, they may be able to negotiate on favourable terms with those French iron-mines who will be feeling the pinch of their diminished trade.

This is only a temporary disadvantage, and it does not, in any case, affect exports to England, particularly in regard to the western ore-fields of France, which in these days of excessive transport charges by rail, are the only ones which would interest British manufacturers.

British metallurgists have continued and will continue to obtain ore from Normandy, Anjou, and Brittany. Even during the present critical period their richness and their proximity to the coast favour their import.

When, within the next few years, or perhaps even the next few months, the Briey ore-field, after having recovered, again resumes the progressive outputs which it made before the war, and when the more economic development of the transport question enable it to load its mineral wealth from French or Belgian harbours, there is very little doubt that the British metallurgical industry will devote attention to this source of supply and will discover the advantages of using these ores, so that there may ultimately be developed a regular traffic of iron ore on the one hand, and of coke on the other, which should take place on a very large scale and with mutual benefit to both countries.

DISCUSSION.

Professor H. LOUIS, Member of Council, expressed the gratitude of British metallurgists to Mr. Nicou for his admirable resumé of the available ore resources of France. Even if his own views diverged from those of Mr. Nicou it would ill become him, in view of his very limited experience of French iron ore mining, to venture to differ from so eminent an authority, nor did he propose in any way to challenge the data set forth in the paper. In fact there was one point on which he was able to give some corroborative evidence. Professor Cayeux held, as stated by the author, that the limbs of the synclines in the Normandy ore deposits went down to very great depths. He had himself made a series of magnetometric measurements in the Segré ore-fields of Anjou, which pointed to the conclusion that, in that field at any rate, the bottom of the syncline would be found lying at a very great depth, probably several thousand metres, and he was thus able to confirm the views of Professor Cayeux.

The point, however, which he particularly wished to discuss, and which he did venture to suggest that his experience entitled him to, was that enunciated in two passages of Mr. Nicou's paper. On p.15 the author stated, "One feature, however, remains the same, and that is the need of Great Britain for foreign ores," and again, on p. 16, Mr. Nicou stated: "Great Britain must for many years to come remain dependent upon foreign countries for her ore supply." On that point, namely, on the question whether Great Britain needed imported ores, he ventured to differ entirely from Mr. Nicou, who, he would suggest, had been misled by the position of British ore imports before the war. In the iron age (the pre-steel age) Great Britain produced all the ores she needed for her then important iron industry, those being almost exclusively Coal Measure ores. Then came the invention of structural steel, first developed in Britain, by, of course, the acid process, and British steelworks were all built to work that process. Owing to the fact that many of the important coal-fields lay close to the sea shore and had excellent harbours, many of the principal steelworks were close to the seaboard and well situated for importing ores. Great Britain was the first nation to introduce railways; as everyone knew, pioneer work was always costly, and on that account British railway freights had always been relatively high. On the other hand, they had an admirable mercantile marine and were large exporters of coal, so that cheap return freights could be secured for iron ores, and that rendered the importation of ore into British works easy and cheap compared with the inland carriage of British ores. In England, as also in France and indeed in Germany as well, the bulk of the native ores were phosphoric ores, and as a matter of fact

Great Britain was proportionately better off for Bessemer ores than either France or Germany. Even so, Great Britain had insufficient Bessemer ore to supply the whole of her works, and therefore began to import such ores on a big scale. Such importation being cheap and convenient, the acid process held its ground in Great Britain even long after the basic process had been brought out, although that too was a British invention. As was well known, in the years immediately before the war, about one-third of the ore supplied to the furnaces of Great Britain was imported ore, and that fact had led the Continent generally to believe that England was short of ore. That was the opinion that Mr. Nicou had voiced in his paper. He (Professor Louis) maintained, however, that it was not because England was deficient in iron ores, but because it was found cheaper and more convenient to import ores that they continued to do so, and had therefore continued to adhere as long as they had done to the acid process. Then came the war and with it the serious difficulty of continuing to import foreign ores. That led Great Britain to develop the home production of ores and that was done very successfully. Whereas before the war, as was well known, the production of steel was mainly acid, since the war they had turned over, and the production of basic steel now preponderated, and that preponderance was tending to increase steadily.

He would remind them that in discussing figures for ore reserves England was in one respect at a disadvantage. In France ores were the property of the State, and the highly efficient French Department of Mines and Geological Survey made it their business to ascertain correctly the iron ore resources, the property of the French nation; but in Great Britain, where the ores belonged to the proprietors of the surface, investigations were only made as and when the need arose, and were then made on behalf of the individual owners. It was only quite recently that the British Geological Survey had attempted to study the mineral resources of the country, and, therefore, in Great Britain the ore resources were not known with the same accuracy as they were in France. The recent investigations above referred to showed that Britain had in Mesozoic iron ores alone, workable to-day under existing economic conditions, some 3400 millions of tons which were fairly comparable with the 5000 million tons estimated by Mr. Nicou for Lorraine. If Britain had in those ores alone two-thirds as much as France, that could not be characterised as poverty or anything like it. Some of the British Mesozoic ores were decidedly low grade, but the best of them, like the Northamptonshire ores, which formed the bulk of the Mesozoic ores, were ores not much inferior to the Lorraine ores, seeing that in the calcined state they contained 47 per cent. of iron and 14 per cent. of silica.

In addition to those, there were enormous reserves of Coal Measure ores which the Geological Survey put down at over 7000 million tons, but he himself had not the slightest hesitation in saying that the Survey had greatly under-estimated the British ore resources of the Carboni-

ferous Series. He did not urge that that mattered very much, because under existing economic conditions those ores were not workable. Their existence, however, should be recorded because they were there, and nobody to-day could say that ultimately those ores might not again prove to be of economic importance.

The point that he wanted to bring out was that if British ironmasters imported ores, they did so because it was to their economic advantage to do so and not on account of any poverty or deficiency of domestic ore supplies. He was anxious to impress those facts upon their French friends, who, he thought, had not fully appreciated the position. He did not for a moment mean to say that the importing into Britain of ores would cease, but that the nature of the ores that Britain was seeking for would be somewhat different in the future to what it had been in the past. The demand for ores low in phosphorus would become less insistent, but what they would have to seek for would be rich ores that would enable them to burden their blast-furnaces so as to enable them to work with the minimum quantity of coke. The relatively high prices that coke would probably fetch in the future made it imperative to seek furnace burdens workable with a low coke consumption, and he thought that the future of British ore import would lie in the direction that he had indicated, and that British demands would be for ores that could be imported cheaply in competition with domestic ores, and at the same time give a low coke consumption in the blast-furnace.

Mr. H. K. SCOTT (London) said they were greatly indebted to Mr. P. Nicou for preparing a paper so replete with valuable information regarding the iron ore deposits of France. He doubted, however, if the statement regarding the value of Lake Superior ores was correct.

Professor Louis had rightly pointed out that the iron ore reserves in England of similar quality were large, but it should be remembered that they were, speaking generally, farther distant from steel-producing centres than those of the east and west of France, which were practically in the same area as the blast-furnaces smelting them.

It had been suggested that the iron ore beds of Western France were thicker and richer near the more important faults, which coincided with the principal valleys, than on the uplands. Could the author give further information regarding that matter? In the Northants and Oxfordshire areas, it was generally considered that the ironstone beds were similarly of less value under heavy cover than near the outcrop. The deposits of the Briey district had been discovered and surveyed by boring, and that method of development might, with advantage, be carried out on the Midland ironstone areas of England. He did not consider that iron ores from the east of France could compete with those from other parts of the world at British ports, unless the mineral was beneficiated in some way, and the present transport charges much reduced.

With regard to the estimates of ore reserves, Mr. Scott asked if the figures were obtained after allowance had been made for poor areas and loss in mining. As work was at present being concentrated on the grey bed in some instances, it was probable that the upper seams, which were considered too poor to work at present, would be lost. Indeed, one writer had stated that the proportion of the iron-bearing formation which could be obtained would not exceed 10 to 15 per cent.

M. FRANÇOIS DE WENDEL (Paris) said that the question of the falling off in quality near the faults had been studied by Mr. Villain, who had written a paper on the subject. They could quite well believe that there was that deterioration of quality, but he thought it was not possible to say that it was definitely proved. His personal opinion was that generally in the Lorraine beds the iron became richer near the faults. He thought the increase was partly accounted for by the fact that the ore in many cases would be taken out from the ground. Very often there were two or three beds of ore of which two were generally good. Obviously the time would come when there would be less ore obtainable and the strata would become thinner.

Sir HUGH BELL, Bart., Past-President, said that before closing the discussion he wished to say how greatly they were obliged to Mr. Nicou and to Mr. Guillaïn for their very interesting papers. The discussion had taken a form which was very interesting indeed, although it did not bear quite directly upon the paper itself, inasmuch as the remarks had to do with the exact economic conditions under which the importation of ore into England would take place. On that point it had been suggested in a sort of friendly way that the Englishmen were not doing their duty. It was extraordinary how easily one's friends could see one's mistakes. Really Professor Louis had given the answer to his own proposition. Englishmen imported ores, when they did so, because on the whole they found it profitable to take that course. No doubt when they found it profitable to work the home ores they would work them, and he thought they were beginning to find that it was profitable. But that depended on a great many considerations which it was difficult to foresee. Owing to the very remarkable improvement in metallurgical practice that had taken place during the past few years there had been a very considerable alteration in the conditions under which importation of ore might take place. If he might take an example from England, he would like them to picture the conditions in some of the Midland counties—for example, Northamptonshire. That county had its ore underground close to the blast-furnaces, and it had to bring between 3 and 4 tons of coal for the purpose of smelting ore and converting the iron into steel. When the ore had been turned into steel it had to be taken to the coast, and that fact had a very important bearing on the discussion.

Those were the considerations to be taken into account when dis-

cussing whether ironworks should be placed inland or on the coast. It seemed to him that the proper situation for English steelworks was on the coast and preferably on the banks of the Tees. He could bring 3 tons of Midland ore to the coast or 2 tons of ore from overseas and smelt it with coal from the county of Durham and take his part in the trade of the world.

The iron trade was essentially an international trade. Their French friends were going to take a very important place in the future in that international trade. Up to the outbreak of war France was nearer than some other nations to being a self-sufficing steel-making power by producing all the steel she required but not having much surplus. The war had altered that, and France in the future would probably be a large seller of steel in the international markets. He was convinced there was trade enough to go round. The world within the next few years would want 70 or 80 million tons of iron and steel per annum, and they as ironmasters, whether they lived on one or other side of the Atlantic, or on either side of the Channel, or on either side of the frontier between France and Germany, relied on that great public demand for the future prosperity of the trade. It was because he believed that the intimate co-operation between the important parties engaged in the trade was desirable that he ventured to add those few words to the discussion on the paper. That discussion had really been upon a larger question than the paper itself purported to bring forward, and they were very grateful to the author for the facts that had been given.

Mr. NICOU, in replying to the discussion on his paper, thanked Professor Louis for having pointed out to him the fresh iron ore reserves which had been met with in England. He had not, however, stated within what period it would be possible to develop them, and there was nothing in his remarks to lead to the supposition that the situation in Great Britain, in regard to the importation of iron ore, would be materially altered within the next few years.

In reply to Mr. H. K. Scott, in regard to his (Mr. Nicou's) statements relating to the Lake Superior iron ore outputs, he had not intended to convey in his original paper that the iron contents of those ores was only 1 or 2 per cent. higher than those of Briey, but that the total output from that region before the war was only 2 per cent. greater than that of the Briey region (30 millions as against 28 millions), when the world production of iron ore was taken into consideration. He (Mr. Nicou) had, however, so amended the text of his paper that that misunderstanding could not again arise.

Iron and Steel Institute.

NOTE ON THE IRON - MINES IN THE BRIEY REGION DAMAGED DURING THE GERMAN OCCUPATION, AND THEIR RE-CONSTRUCTION.

By A. GUILLAIN (PARIS).

It is generally known that the deposit of iron ore termed "Minette" extends through Lorraine on both sides of the old Franco-German frontier, between Longwy on the north, Thionville on the east, Briey on the west, and Nancy on the south. That portion in former German-Lorraine is known as the Thionville field, and lies entirely within the new Department of the Moselle. The portion lying in the Department of Meurthe-et-Moselle is divided into three fields, those of Longwy, Briey, and Nancy. The two former are the prolongation, without discontinuity, of the Thionville field. The mines about Longwy are worked either open or by galleries driven into the hill-side. Those of the Briey region are worked by shafts of 150 to 250 metres in depth; and the Nancy field is isolated from the two first, the ore being worked by galleries in the hill-side.

The present note does not concern itself with the Thionville field, which continued to be worked during the war by the Germans, nor with the Nancy field, which was not invaded, and continued to be worked by the French. It deals only with the Briey-Longwy field, which was invaded by the Germans in 1914 and was liberated in November 1918.

THE MINES OF THE BRIEY-LONGWY FIELD IN AUGUST 1914 AND DURING THE WAR.

At the time of the declaration of war by Germany, eighteen mines were in operation and a new one was in process of being sunk in the Briey field. In the Longwy field fifteen mines and four quarries were in operation. In 1913 the production of

Briey was 15 million tons and of Longwy 3 million tons, the total for the two regions being 18 million tons.

The mines gave employment to about 15,000 workmen, of whom a large proportion were Italians. The total population dependent on the mining industry, including women and children, was about 40,000, housed in the workmen's colonies built by the mine owners.

The distance from Briey to Metz as the crow flies is 20 kilometres, which means that the town of Briey and all the mines between Briey and the frontier were under the guns of Metz.

Before the declaration of war, German reconnaissances had pushed into France, and the French troops had been withdrawn by order 5 kilometres from the frontier, with the object of avoiding a conflict, as it was still hoped that the German Government would be persuaded to avoid war. Thus all the mines along the frontier were at the mercy of the Germans, and the whole of the Briey region was effectively occupied within a few days. The mining companies took what measures they could during the few days when peace was in the balance. Most of the directors and engineers had military obligations to fulfil, and were obliged to depart immediately on the outbreak of war, and only a small number of trustworthy men were left to look after the pumping and maintenance ; all the rest were evacuated and the Italians were repatriated. All roads towards Verdun and Nancy were blocked with emigrants carrying their belongings.

The encounters between troops which took place the first few days brought all pumping to a standstill in three mines, namely, Amermont, Pienne, and Murville, which were drowned out, but the others were still in perfect order in October 1914, by which time the front had been stabilised. During the whole war no further fighting occurred in the mining region, and the Germans could work the mines at their leisure or destroy them.

The German Government then began an economic war based on the interests of the German industry. The steelworks were completely demolished or the plant transported to Germany, but the majority of the blast-furnaces were preserved and shut down. The mines were kept working for the most part, and the ore was sent to Germany until the time came when, the conditions of war having completely changed, they were closed down, and most of the material and stocks carried off.

In the secret memorandum presented by German Associations to their Government during the war, the annexation of the Briey iron-mines was urged as a prime necessity for the assurance of the expansion of the German iron industry. Events have shown that this necessity was entirely relative, for since the war the German blast-furnaces have been able to run without any ore from Briey. But no doubt the Germans, with their immense reserves of coal in Westphalia, were keenly desirous, with a view to increasing their production of pig iron, of acquiring ore reserves corresponding to their coal reserves, and the annexation of Briey was all the more tempting as the ore there is richer by five or six units than that of Thionville.

On the other hand, it was to their interest to concentrate the production of steel in their steelworks in Lorraine and Westphalia, for which reason they destroyed the French steelworks in the Briey district as they did in Northern France.

Moreover numerous proofs exist that the iron-mines were also marked down for destruction, if it should turn out that the Germans would not be able to keep them. A document is given in the Appendix, entitled "Destruction of the Mines of Anderny," which is an exact translation of a paper found at that mine after the retreat. That the destruction of the iron-mines was not completed, as it was in the case of the coal-mines of the North, was only due to the fact that the precipitate retreat left them no time.

THE GERMAN ORGANISATION FOR WORKING THE MINES.

In October 1914 the Germans began the organisation of the district. A central administration was established at Metz, known as "Schutzverwaltung der Bergwerke und Hütten." The first care of this organisation was to transport to Germany the whole of the stocks of iron ore which the French owners had left at the mines. These consisted altogether of about 1,400,000 tons in the two fields of Longwy and Briey.

Local administrations were then created at the various centres, German engineers were appointed to direct mining operations, and the French supervisors left in charge were forbidden to enter the mines. Prisoners of war were drafted there for the work, the majority of whom were Russians and some were English.

They were lodged in huts in barbed-wire enclosures and were harshly treated and badly fed. The workmen's colonies were used to shelter troops passing through, or turned into hospitals, and in some cases into stables. Most of the houses were completely sacked. The military authorities established a strict rule throughout the district, communication between one village and another being strictly prohibited.

During the first year, 1914-15, only a few mines were worked, and their production reached about a million tons. At the other mines much material was carried off, particularly the steel tracks both below ground and on the surface, and the copper trolley wires. The petrol locomotives were sent to the front for military purposes. From 1916 onwards, owing to the continuous rise in the price of Swedish ore and the exchange being less favourable, also in order to carry out the Hindenburg programme, the working in the Briey mines was intensified, and some mines already stripped of part of their equipment were restored. During 1916 eight additional mines, making ten in all, were put to work, and these yielded about 2,600,000 tons. In 1917 the majority of the mines were in operation and the output reached 5,200,000 tons. After the end of that year the output was checked on account of the difficulty of finding workmen, and the tonnage in 1918 did not exceed 4,400,000 tons.

At the same time the pillaging of the mines which were still idle recommenced under the direction of the "Rohma" (Rohstoff und Maschinenverteilungstelle des Kriegsamts), which was established first at Metz and afterwards at Longwy. In some of the mines the whole of the equipment of the power station and all the machine tools were despatched to Germany.

Nevertheless, in spite of the efforts of the Germans and owing to the scarcity of workmen, the output which had exceeded 18 million tons per year before the war, amounted only to 13,300,000 tons for the whole of the four war years. The whole of the ore was despatched to the Rhine Province, and some of it sent on to Silesia. The exploitation of the mines by the Germans was badly performed, their only object being to intensify the production. They mined the ore in the prepared sections without doing further preparatory work. They also robbed the ore in the neighbourhood of the principal galleries and shafts. On this

account the mines suffered serious damage which is in some cases irreparable. In particular the inrush of water was considerably increased. The flow in the whole of the eighteen mines amounted to 74 cubic metres per minute in 1914, and it had reached 81 cubic metres per minute in 1919. The mines were therefore altogether in a deplorable condition when the French owners returned in November 1918, and were able, after four and a half years' absence, to enter on their property again. Nevertheless, it was a great satisfaction that their fears of complete destruction, similar to that carried out in the coal-mines of the north, had not been realised, and with great energy they set about the necessary repairs.

ESTIMATION OF DAMAGES.

In the first place it was necessary to estimate the damages caused by the German occupation in order that the French Government might take up the question of compensation. The estimates were made under the control of the Ministry of Mines of the State.

Every mine was ordered to prepare a detailed schedule of all damaged plant and workings, in which was entered the 1914 value of every article and the estimated cost at the present day of its repair or replacement. The sum total of the damage at the mines of Briey and Longwy, agreed by the Ministry of Mines, after discussion with the owners, amounted to 120,763,000 francs as the 1914 value, corresponding to a 1920 valuation of 429,465,000 francs. Over and above these direct damages, damages arising out of the direct consequence of the war were also estimated. In this category are included the cost of pumping water during the reconstruction, while no ore was being got, and the loss of revenue resulting from stoppage of work during the period of reconstruction. These losses altogether exceed 120 million francs.

COMMISSION FOR THE ASSESSMENT OF THE DAMAGES.

Although the costs of reparation have been checked in most minute detail for every mine by the Government mining engineers, the final estimate will be by the Tribunals of War Damages established in every Canton, and called "Cantonal Commis-

sioners." The French State having undertaken to make advances to the owners for the reparation of their direct damages, a representative of the State will appear with the owners before these "Cantonal Commissions" to give evidence.

With regard to the damage, which, although arising as a direct consequence of the war, does not come under the category of break-downs, destruction or removal, and on account of which the French State grants no advance to the owners, these have been submitted for examination to the Inter-Allied Commission of Reparations. In most cases the proprietary companies were obliged to raise loans at their own expense for the reparation of their damages, pending the receipt of advances from the State. Needless to state, although two years have passed, no payment has yet been made by the Germans to the damaged mines towards the replacement of all the material which they removed, towards the reparation of what they destroyed, nor towards the compensation for the war contributions which the occupying troops extorted in the district.

RESULTS ACHIEVED IN THE REPAIRING OF THE MINES.

After the Armistice the mining companies started at once on the work of repair, but the difficulties will be realised when it is remembered that the whole region was reduced to a state of devastation after four and a half years of complete isolation and uninterrupted occupation by the German troops. The staff of workmen who had remained at the mines had their health broken by all kinds of hardships which they had endured for so long. Their efficiency was greatly diminished, and those of the staffs who had escaped to France were still mobilised or were dispersed in other mining districts. The difficulty of collecting the staffs was increased by the fact that all the houses were uninhabitable, and the railways did not run until April 1919. Until that date the country was occupied by American troops, and the railway capacity was entirely absorbed by military transport and the provisioning of the Armies on the Rhine. The material for reconstruction, scarce as it was, could only be brought in with the utmost difficulty. In spite of all, the houses for engineers, staff, foremen and workmen for the repairs were gradually put

in order. The boilers, steam-engines, and electric machinery which had been broken down or removed bodily to Germany were repaired or replaced. A further hindrance to the work was due to the disappearance or wilful destruction of plans, drawings, and correspondence. The petrol locomotives which had been carried off were replaced by similar engines found in the German dépôts at the front. These were modified and adapted to the gauge of the mine tracks. Many kilomètres of track, pipe lines for the compressed air, and trolley wires for electric locomotives were relaid in the galleries and workings.

On account of the magnitude of the orders for material to be placed, the iron-mines joined with the ironworks in forming a purchasing association called *Le Société Corporative des Mines de Fer et Usines Sinistrées de Meurthe et Moselle*. This company was recognised by the State as an intermediary organisation between the damaged mines and another organisation known as *Central Comptoir of Purchases for the Invaded Regions*, commissioned by the Government to buy all the material required for the advances in kind made to the manufacturers of the invaded territory.

The *Central Comptoir of Purchases* was not a State Department, but a private limited company, the shareholders of which were the manufacturers themselves, and it was under their management; but it operated under the control of a State organisation known as the *Office of Industrial Reconstruction*. A large proportion of the orders placed by the *Comptoir* was prepared by the manufacturers themselves. It was the function of the *Comptoir* to verify whether the terms of purchase were acceptable or could be moderated.

The *Comptoir* keeps account of these orders for the State, receives cash from the State and delivers the material to the firms up to the amount of the advances agreed by the State in respect of the indemnity for war damages. With the aid of this organisation the mines in Eastern France have been enabled to receive advances from the State up to about 75 per cent. of the damages of the first degree agreed by the Ministry of Mines. The advances have been made partly in kind in the form of material and equipment ordered through the *Société Corporative* and the *Central Comptoir of Purchases*, partly by means of

drafts sanctioned by the Ministry of Mines up to the amount of the credits opened by the Ministry of the Liberated Regions. The functions of these organisations have been performed in a satisfactory manner, and a thorough control of the expenditure of money on reparations has been assured. Owing, however, to the bad faith of the Germans in not paying for the devastation committed by them, the sums necessary for the reparation have had to be advanced by the mining companies, and these have been obliged, notwithstanding the losses suffered by the French Savings Banks, to contract loans in France. The French Government, provisionally undertaking the obligations of the German Government, has only been able to pay over a proportion of the costs incurred by the mining companies in repairing the damages. At the present moment the assistance of the State has been checked by want of cash, and the work of reparation is to some extent stopped.

The efforts made by the mining companies and by the French State will be appreciated when it is considered that the actual expenditure of the companies on the mines, partly met by the French State, amounted at July 1, 1921, to about 150 million francs. It may be said that in addition to this outlay the mining companies have repaired the plant and replaced the material carried off to an extent which will enable them to reach the pre-war output of ore as soon as the necessary labour has been recruited. There are, however, still a number of machines on which nothing has been spent for upkeep for four and a half years, and others have been badly used by the Germans who had no interest in their preservation. Such machines will never be able to reach their former efficiency, and the cost of working will consequently always be higher than before the war. It is certain that the mines will never be completely indemnified, on account of the addition to the cost of working and the extra pumping necessary to keep down the increased volume of water, all of which adds to the cost of every ton of ore.

With regard to labour, all the French and Italian workmen had left the mines in 1914, flying before the invasion, and the German engineers had carried on the work with practically no other labour than Russian and English prisoners of war. Directly the Armistice was signed all these prisoners left the country and

the mines were suddenly deserted. The companies find themselves obliged now to seek new workmen in France and particularly in Italy, and to train them afresh.

There are many difficulties in the way of the rapid training of the workmen, especially the impossibility of housing them until the dwellings are repaired. For this work the material was very scarce and the railways were only transporting material sufficient for the needs of the population, the roads being completely cut up. Much of the labour had to be obtained abroad, principally from Italy, and the Italian Government was preventing the emigration of its Nationals at that time. Nevertheless, within a year of the recovery of the mines by their owners, by December 1919 about 5000 workmen had been recruited as compared with 15,000 before the war. At the end of 1920 the workmen numbered about one-half of the pre-war establishment, and the houses were by this time almost entirely rebuilt or repaired. It would have been possible to increase the numbers if the market conditions had permitted an increase in the output.

The following figures show the progress in the output of the Briey-Longwy fields as the result of the efforts of the mining companies :

	Tons.
Output in December 1918	0
„ „ January 1919	14,000
„ „ July 1919	45,000
„ „ January 1920	177,000
„ „ July 1920	370,000
„ „ January 1921	500,000

At the beginning of 1921 the output had therefore risen to over one-third of the pre-war tonnage.

The yearly output in the same fields has been :

1913	18,000,000 tons
1914-1918	(In exploitation by the Germans)
1919	835,000 tons
1920	4,190,000 „

Complete statistical information on this matter has already been published elsewhere.

Table No. II shows the monthly increase in output from January 1919 to December 1920 for the whole of the mines.

To complete the information some details are given for the three mines which were flooded throughout the war. Out of

eighteen mines in operation in 1914, fifteen have contributed since 1919 to the present total output ; the other three mines, being in the fighting zone for a few days, were flooded by stopping the pumps. The German military authorities suspected that signals might be given by means of the smoke from the chimneys, and therefore ordered the fires to be drawn. The water rose to within 40 metres of the surface, the depth of the shafts being about 200 metres, and the total volume of water to be pumped out was about 7 million cubic metres. The two mines of Pienne and Amermont are now unwatered and Murville mine will soon be cleared. The work of pumping out each mine took from five to six months, using two electric pumps of 5 to 6 cubic metres capacity per minute, together with tubs of 6 cubic metres capacity lowered and hoisted by the winding engine. The water was removed at the rate of 13 cubic metres per minute, taking account of time lost. The daily flow to be pumped in each mine after it is cleared is 5 to 6 cubic metres per minute. The total cost of unwatering these three mines may be put at 15 million francs, including cost of the special plant. All the plant below ground, pumps, pipes, fans, locos, rails, tools, &c., is much injured by rust, and is practically useless. Considerable falls have occurred in the galleries and workings, causing a loss of much ore, but the seams for the most part have not been rendered unproductive, as might have been feared. In a few months the whole of the mines will have been restored to working order.

In conclusion, something may be said concerning the economic conditions affecting the sale of the ore. The war not only brought about the destruction of the plant and dispersal of the labour, but for four years all relations with the regular clients were suspended. This has profoundly modified the former channels for marketing the ore, and the mine owners have therefore to reconstruct their markets.

The table on next page shows the localities in which the ore raised in the Briey, Longwy, and Nancy fields was consumed.

Considering the Briey field alone, which yields the richest calcareous ore, and consequently the most suitable for export, it is seen that of a total of 14,840,000 tons raised, a little more than half (7,680,000 tons) was consumed in France. Next in order is Belgium, with Luxemburg and Westphalia taking nearly

the same quantity. Then Lorraine, formerly German, and lastly Great Britain.

The blast-furnaces of Meurthe-et-Moselle are not in a position to use much of the Briey ore because the basic steelworks were

TABLE I.—*Consumption in 1913 of Ore raised in Meurthe-et-Moselle (in 1,000 tons).*

Where Raised	Briey.	Longwy.	Nancy.	Total.
<i>Where consumed :</i>				
Meurthe-et-Moselle	6,000	2,005	1,512	9,517
Other French Depts. . . .	1,680	133	52	1,865
Lorraine	490	270	54	814
Belgium	4,416	175	105	4,696
Luxemburg	1,142	58	...	1,290
Westphalia	976	4	182	1,162
Great Britain	70	...	...	70
Various	66	...	...	66
Totals	14,840	2,645	1,905	19,391

destroyed by the Germans and have not been fully rebuilt. The works in Northern France are in the same case, and it was there that the greater part of the ore used in France, outside Meurthe-et-Moselle, was formerly consumed. It will probably be two years before the reconstruction of the steelworks and rolling-mills is complete.

In Belgium the destruction was not so complete as in France, and the former productive capacity of the works has been nearly re-established. It is only due to the trade depression that the works there are not in full activity. The same cause influences unfavourably the consumption of Briey ore in Luxemburg.

For all these districts there is one underlying reason for the falling off of the export of ore, namely, the high railway freights, which are four or five times greater than before the war. This factor affects the consumption in Meurthe-et-Moselle, since the works around Nancy prefer to use the lean ores in their own neighbourhood instead of transporting the Briey ore. It affects Luxemburg and Belgium, because the cost of transport of the Luxemburg ore is lower, giving an advantage to the lean ores of Luxemburg. It affects the Lorraine works, which like-

wise prefer to use the ore at their own doors. Finally it affects still more the sales to Westphalia and most of all to Great Britain. In 1914 special rates of 6 francs per ton of ore for shipment to England were in force from Briey to Dunkirk, and the freight is now 22 francs.

Trials of the ore in England had given very satisfactory results, and though the economic crisis of 1914 had interrupted the export, negotiations were in progress for the supply of ore in large quantities to works proposing to instal the basic process. A study of the means of transport and handling of the ore had shown that with special waggons forming trains of 1500 to 2000 tons, and with suitable apparatus for loading ships, it was possible to reduce greatly the cost of transit from the mine to the ship. The same considerations still hold good, and there is no doubt that if the French railway companies are fully alive to their interest in this question, it will be possible to inaugurate an important export trade to England.

In fact one consideration dominates the whole problem. England possesses large resources of coal and France possesses extensive resources of ore, the distance which separates them being comparable to that which is traversed in the United States at extremely low transport rates by the raw material intended for the manufacture of pig iron. The Briey ore is not very high grade, but its smelting qualities and its chemical composition caused it to be highly appreciated in the tests made in England before the war. Without doubt in the future important quantities will be exported into England, the result depending entirely upon the economic question of transport and handling.

It will be noted that throughout the whole of 1919 the restoration of machinery and repair of workings was being carried on in all the mines of the Longwy-Briey field.

During the first two months only two mines were in operation : Joeuf and Errouville. The following mines were successively brought into operation on completion of the repairs :

In March	.	.	Moutiers.
„ May	.	.	The Mine of Landres and Homécourt.
„ August	.	.	Mouriere.
„ September	.	.	Joudreville.
„ October	.	.	Jarny.
„ November	.	.	Droitaumont and Anderny.

The output of the mines and workings in the Longwy field also increased as the work of restoration progressed. In the accompanying table the output of the Longwy field represents

TABLE II.—*Showing Monthly Rate of increased Output of Ore from the Mines of Longwy Briey Field, according as the Work of Reparation progressed in 1919-20.*

	1919.	1920.
January . . .	14,090	177,725
February . . .	21,242	201,394
March . . .	25,367	248,990
April . . .	34,310	271,282
May . . .	47,272	274,965
June . . .	27,322	340,962
July . . .	45,143	369,767
August . . .	27,322	391,345
September . . .	86,654	442,748
October . . .	110,270	465,754
November . . .	149,196	475,809
December . . .	182,300	520,668
Totals . . .	770,488	4,181,409

20 to 30 per cent. of the figures shown for 1919, and about 15 to 20 per cent. of those shown for 1920.

In December 1919 there were still seven mines which had not yet been brought into operation. Out of these seven, three were flooded (Pienne, Murville, Amermont), one was still in process of being equipped, and the three others, namely, Sancy, St. Pierre-mont, and Valleroy, were started respectively in February, March, and November 1920.

APPENDIX.

TRANSLATION OF A GERMAN DOCUMENT.

July 4, 1917.

Destruction of the Anderny Mine in case of a break-through on the front.

TO THE IMPERIAL ADMINISTRATOR OF MINES, HOMÉCOURT.

DIVISION A.

Attached hereto we submit to you a statement showing the time and the number of workmen necessary for the destruction of the mine of Anderny in case of a break-through on the front.

Directorate of Anderny Mine.

(Signed) JOESTEN.

SECRET.

ANDERNY MINE, July 4, 1917.

Statement of the work necessary for the destruction of the mine of Anderny in the case of a break-through on the front, and the waggons required for the removal of the more important material.

1. *Destruction requiring a period of three-quarters of a year to make good.*

Removal of pumps.

Blocking of shafts Nos. 1 and 2 by throwing in the cages and tubs after cutting the cables.

Destruction of the pulleys and the winding-engines.

2. *Destruction requiring one and a half years to make good.*

As above.

In addition, to blow up the whole winding plant, engine-house, foundations of the winding-engine, and the stock bins.

3. *Permanent Destruction.*

As in No. 2.

In addition, destruction by dynamite of the shaft-lining.

To blow up completely the head-gear, stock-bins, to burn the wood tower of shaft No. 1.

To wreck all constructional work at shaft No. 2.

For the first case 10 men are required, time 24 hours.

„ „ second „ 20 „ „ „ „ 36 „

„ „ third „ 32 „ „ „ „ 60 „

Twenty-five waggons will be required for the transport of the material, without counting those which would be necessary to remove the coal and ore, of which the quantity will be fixed according to the demands.

ANDERNY MINE.

Director (Sgd). JOESTEN.

Iron and Steel Institute.

ON THE POSITION OF THE METALLURGICAL INDUSTRIES OF NORTHERN AND EASTERN FRANCE: THEIR DESTRUCTION AND RECONSTRUCTION.

BY L. GUILLET (PARIS).

INTRODUCTION.

THE object of the present paper is to describe the conditions now prevailing in French metallurgical works as the result of the war, and their destruction and reconstruction will be described in turn. Greater emphasis will, however, be laid on the second phase, as the *Revue de Métallurgie* has already published lengthy accounts of the destroyed works, and the present author has written a summary that may well serve in itself as a memoir and introduction to those sad annals.

I. THE DESTRUCTION OF FRENCH METALLURGICAL WORKS.

It is of interest to note, in the first instance, the situation in which France found herself as the result of the invasion, that is, so far as her metallurgical needs were concerned.

The French production of coal in 1913 was 40,844,000 tons, and 50 per cent. of this production was from the occupied regions. The iron ore production in 1913 had risen to 21,918,000 tons. Of this amount 83 per cent. was mined in the invaded regions. The pig iron production was 5,207,000 tons, of which 3,560,190 tons were produced in the East and 933,089 in the North. Of the total, 64 per cent. of the productive capacity passed into enemy hands. Finally, of a total steel production amounting to 4,934,000 tons, 2,528,630 tons were made in the East and 1,165,888 tons in the North. By reason of the situation of the works, 63 per cent. were on the side of the battle-front farthest removed from France. The following list enumerates the principal ironworks destroyed, but it should be noted that this list only comprises works making pig iron and steel, and does not include

foundries, some of which, like those of Messrs. Muller & Roger at Noyon, were exceedingly important. Nor does it include engineering works having subsidiary metallurgical shops, although, as in the case of the Société Française de Constructions Mécaniques (Anciens Etablissements Cail) at Denain, some of these were of considerable size.

Name of Works.	Plant.	Output and Number of Workpeople.
Etablissements Arbel Hauts-Fourneaux de la Chiers	5 open-hearth furnaces, important forge and hammer shops, 4 blast furnaces, 3 converters, rolling-mills	300 tons of steel, 2100 workmen, 82,000 tons of pig iron
Hauts-Fourneaux, Forges et Aciéries de Denain et Anzin.	8 blast furnaces, 4 converters, 10 open-hearth furnaces, 12 puddling furnaces, rolling-mills and foundries	334,677 tons of pig iron, 396,262 tons of steel, 6500 workmen
Usine de l'Espérance .	4 blast-furnaces, 12 puddling furnaces, converters and rolling-mills	142,843 tons of pig iron, 152,825 tons of steel, 1900 workmen
Société Métallurgique de Gorcy Aciéries de Longwy .	blast - furnaces, forges, and wire mills 9 blast-furnaces, 6 converters, rolling-mills and foundries	.. 364,680 tons of pig iron, 314,234 tons of steel, 6744 workmen
Usine d'Homécourt .	7 blast-furnaces, 4 converters, 2 open-hearth furnaces, rolling-mills, &c.	453,650 tons of pig iron, 345,000 tons of steel
Aciéries de Micheville .	6 blast-furnaces, 4 converters, rolling-mills and foundries	389,599 tons of pig iron, 208,832 tons of steel, 3000 workmen
Aciéries du Nord et de l'Est	7 blast-furnaces, 5 converters, 2 open-hearth furnaces, rolling-mills, &c.	242,890 tons of pig iron, 192,308 tons of steel, 4800 workmen
Forges et Aciéries de Pompey	4 blast furnaces, 3 converters, 1 open-hearth furnace, rolling-mills, and forge and foundries	..
Hauts - Fourneaux et Fonderies de Pont à Mousson	8 blast-furnaces, 26 cupolas, foundries and coke-ovens	285,000 tons of pig iron, 179,000 tons of castings, 6200 workmen
Société Métallurgique de Pont-à-Vendin	3 blast-furnaces, steel-works and rolling-mills	..

Name of Works.	Plant.	Output and Number of Workpeople.
Usines de la Providence (Hautmont et Rehon)	3 blast-furnaces, 3 open-hearth furnaces, rolling mills and foundries	196,000 tons of pig iron, 220,000 tons of steel, 2300 workmen
Etablissements Raty et Cie	4 blast-furnaces, foundries	94,677 tons of pig iron, 335 workmen
Etablissements de Saintignon et Cie	5 blast-furnaces.	173,393 tons of pig iron
Société Métallurgique de Semelle-Maubeuge	7 blast-furnaces, steel-works, open-hearth and Talbot furnaces, rolling-mills, foundries	4250 workpeople
Société Lorraine Industrielle	2 blast-furnaces	51,702 tons of pig iron, 125 workmen
Forges de Vireux-Molhain	Open-hearth furnaces, rolling-mills, foundries	91,319 tons of finished products, 1200 workmen
Etablissements de Wendel	8 blast-furnaces, 6 converters, rolling-mills	393,723 tons of pig iron, 330,207 tons of steel, 2383 workmen

Amount of Material removed by the Enemy from Ironworks.

1. Plant and Machinery.

	Tons.
Pig iron, wrought iron, and finished steel	50,850
Copper, bronze, aluminium, lead, and zinc	247
Machine tools and shop tools	457
Overhead cranes	737
Electrical machinery	1,768
Window-glass	28
Wood	295
Indiarubber, leather belting, and ropes	12
Refractory materials	1,927
Total	56,321

2. Stockyard Material and Finished Products.

	Tons.
Pig iron, iron, and steel	22,776
Iron ore	723
Manganese ore	3,292
Fuel	2,305
Slag and waste	11,417
Steel scrap	3,341
Refractories	1,557
Miscellaneous stores	5,346
By-products	1,172
Total	51,429

A point that requires emphasising is that of all this destruction only a very small proportion was due to actual war damage. The bulk of this destruction was deliberate, and had as its object the putting of French ironworks out of action for many years to come. In support of this statement may be adduced such facts as that in works situated along the actual firing-line, whose destruction might otherwise be attributed to war damage, dynamite cartridges are known to have been used to destroy all the producing plant, such as furnaces, rolling-mills, and hammers. The author has himself removed, at the Biache Saint-Vaast Copper Works, near Arras, a whole series of high explosive cartridges from the principal parts of the plant and machinery.

In regard to works situated at a considerable distance from the front two distinct periods are noticeable, more especially in the case of works in the Sambre. Soon after the invasion the enemy encouraged the captured workpeople to continue in work, and proceeded with the completion of workshops and plant then in course of construction. At, however, the beginning of 1916 came the period of a general inspection of the invaded works, when note was taken of which works should be destroyed and which should be despoiled. Shortly afterwards the work of destruction was commenced ; entire shops, pillars, girders, and roofs, as well as shop tools, were removed, and what could not be taken away was, generally speaking, destroyed. In some regions so systematically was this destruction carried out that a whole arsenal of works-breaking machinery was created for the purpose. In a number of works the overhead travellers were called into service to drop heavy tups all over the machinery, floors, and foundations, wherever, that is, they could reach.

II. RECONSTRUCTION.

The work of reconstruction has been truly remarkable, taking into consideration the conditions under which it had to be undertaken. After the Armistice it was impossible to rely on finding anything that might be needed in the immediate locality. Everything had been systematically destroyed or stolen. Machinery, raw materials, and labour were lacking, and the workmen were

scattered far and wide. On the other hand, the lack of coal and of means of transport made it impossible to rely on the regions still intact, besides which, the latter, suddenly diverted from the manufacture of munitions to the requirements of peace, and with very meagre resources, could not for a long time be expected to grapple with the heavy demands with which they met. Indeed, by a paradoxical position of affairs, it was the very works to which firms more in the centre of France would ordinarily have looked to provide coal and ores which were themselves most in need of material and fuel for their own reconstruction.

Details will be given of how this situation was met, and of the results accomplished.

*Société Anonyme des Hauts-Fourneaux, Forges et Aciéries
de Denain et d'Anzin.*

This company had suffered very seriously. At the commencement of 1921 only two workshops were at work, the refractory products department and the iron foundry. These departments were housed in two main buildings, each 120 metres long and 15 metres wide, provided with six overhead cranes of a capacity varying from 6 to 40 tons. By March 1921 the production of refractories had reached 820 tons, while in the foundry 400 tons of iron castings and 40 tons of steel castings had been produced. This represents, however, but an infinitesimal part of the work of reconstruction. Foundations and constructions had already been put in hand to a value of 63,000,000 francs, and orders placed for further plant to the value of 103,000,000 francs. These orders include four blast-furnaces of 300 tons capacity, with Stahler bin chargers (of which the first furnace will be blown in this year), four 30-ton basic converters, and a reserve mixer of 500 tons; four 40-ton open-hearth furnaces with two mixers, one of 150 tons and the other of 50 tons; a central power station, the building of which is already finished, and the plant for this power station, comprising seven 4100 horse-power gas-engines, seven 3200 kilowatts alternators, and four gas blowing-engines of 1000 m.³ capacity at 0.50 m. mercury. The recuperation of the heat of the gases escaping from the gas-engines will be undertaken in boilers and in turbo-alternators.

Société des Aciéries de Longwy.

The efforts put forth here have been no less considerable. Formerly the company possessed nine blast-furnaces, seven at Mont-Saint-Martin and two at Moulaine, six kilometres from the steelworks and connected therewith by a private railway. The whole plant was systematically pillaged and destroyed. The Moulaine furnaces were restarted in July 1919 and a furnace was blown in at Mont-Saint-Martin in January 1920. Two more followed in April and July, and seven are, at the present moment, either working or ready for blowing in. Occasion has been taken to replace the blowing-engines destroyed by much more powerful new ones, and the capacity of these seven blast-furnaces which before the war was 32,000 tons per month, has now risen to 38,000 tons per month.

The open-hearth plant contained twelve gas-producers, one 350-ton mixer, three 60-ton tilting-furnaces, and two 20-ton fixed furnaces. It was served by fourteen overhead cranes and had just been completed when war broke out. The producers and the mixer have disappeared, while of the open-hearth plant only the dismantled shells of the two fixed furnaces remain. The structural steel work of the shops were, for the most part, demolished, and the steel members cut up by means of the blowpipe and despatched into Germany. The overhead cranes, with the exception of two, were taken away. The two that remained were kept for the purpose of stripping and loading up the material pillaged from the works.

Here again work has begun. The first 25-ton open-hearth furnace was put into operation in July 1920, and the second in September of the same year. The structural steel work and overhead cranes have been restored, as well as one of the 60-ton tilting-furnaces, which has been completely rebuilt. This open-hearth department is already capable of producing 8000 tons of open-hearth steel per month. Within five or six months its reconstruction will be complete and its monthly capacity will then reach 15,000 tons.

The basic steel department comprised two 200-ton mixers, and three 18-ton and four 25-ton converters. The latter, only

installed in 1914, had not, at the outbreak of the war, been got to work.

After the Armistice the condition of the plant was as follows : Of the mixers nothing but the shells remained. The three 18-ton converters had been demolished and the four 24-ton converters had been removed to Germany, as had also a 20-ton overhead crane, part of the roof and the whole of the basic shop plant. The charging machines, the cupolas, the overhead transporters, the lime bins, and most of the floor plates had been destroyed, as well as one of the blast blowing-engines and the four compressors. Of the accessory plant, such as stripping cranes, ladles, ingot moulds, capstans, slag crushers, &c., nothing escaped either destruction or removal.

The first care of the company after the Armistice was to recover the four 24-ton converters which had been taken to recovered Lorraine. Thanks to ceaseless work, these four appliances were restored by July 1920, and on August 16 the first charge was blown.

Rolling-Mills.—Whereas in the blast-furnace and steel departments some little salvage remained, the fourteen trains of rolls working in 1914 were systematically pillaged or destroyed. The problem of reconstruction was therefore more complicated, as it was impossible to recover the fourteen mills and their accessories. The first care was to put in order the blooming-mill, the heavy sheet-mill, and the semi-continuous, the principal parts of which had been stolen but were recoverable. Reconstruction to this extent would allow of some degree of rolling down the steelworks output. This programme was sedulously followed in face of innumerable difficulties, for not only had much accessory plant been destroyed, but the mill parts recovered from Germany had suffered enormously in the course of dismantling and removal. Despite all these difficulties the company were able to start these three mills in July 1920. There still remain to be reinstalled the whole of the sheet and section mills to replace those destroyed. The company will profit by the occasion by introducing all the most recent improvements and thus creating a plant corresponding completely with the latest metallurgical practice and with the economic conditions which the post-war situation imposes. The whole of this plant

is on order, and much of it would have been put down by now had the contractors been able to keep their engagements. Thus, in less than two years a new works has arisen on the ashes of the old, not, it is true, complete, and still far short of what it was before the war, yet forming, as a whole, a unit capable of producing, monthly, 20,000 tons of rolled steel. When the whole is complete, the immense efforts put forward by the Longwy Company with and from practically its own resources, will very appreciably increase the pre-war production and will be derived wholly from modern plant possessing the most recent improvements.

The company's efforts have not, however, been limited to the reconstruction of its Mont-Saint-Martin plant. With the object of further transforming its products, the company in 1919 purchased the Forges de Sedan, which had long enjoyed a reputation for thin sheets, a department of manufacture which it was not found possible to provide room for at Mont-Saint-Martin owing to the large area which has been devoted to the reconstruction of the mill plant at that works. On the site of the old forge at Sedan will be built an entirely modern works, for which orders were lodged within the first few months of 1920, and of which the erection has already commenced.

Société Anonyme de la Providence.

The Rehon works near Longwy were in great part destroyed and dismantled. Of the three blast-furnaces, however, two were not beyond repair, and on May 23, 1919, one was blown in again, and the second was similarly got to work on October 14th in the same year. For this purpose a 500-kilowatt electrogenerative set and a blowing-engine had to be repaired. From October 15, 1919, to August 15, 1920, the various central power station engines were got to work.

The basic steel plant, which had been entirely dismantled, was recovered from the Sarre district, as well as the rolling-mills. The first cast was poured at the steelworks on November 18, 1919, less than a year after the liberation of the works. On June 8, 1920, the electric mill drive was first started, and by the end of the month the first blooms were being sent out. By

November 30th in the same year the 950-millimetre mill was in operation. Two years had been found necessary to repair the plant installed in 1910-1911. Besides this, over 8000 tons of material stolen by the enemy had been recovered.

Compagnie des Forges et Aciéries de la Marine et d'Homécourt.

The Homécourt works, which were amongst the most important in France, comprised blast-furnaces, steelworks, rolling-mills, and all accessory plant.

Out of seven blast-furnaces provided with twenty-nine Cowper stoves, and capable of producing 1200 tons of pig iron per day, two have been restarted. The two 1000-horse-power steam blowing-engines and the five 1200-horse-power gas blowing-engines have been replaced by two 1700 horse-power gas-engines and a 2000-horse-power turbo-blower, installed as a temporary measure. Two 160-ton mixers were destroyed. They will be replaced and reinstalled at the steelworks. Out of fifty-six boilers giving 7360 m.² heating surface and supplying steam for the blast-furnace blowing-engines, the steelworks blowing-engines, and the blooming and reversing mill engines, only thirty, with a heating surface aggregating 3000 m.² remained, the rest having been either removed or destroyed.

The basic steel works, consisting of four converters of 17 to 21 tons capacity, capable of producing 1200 tons of ingots daily, the basic shop and all the accessory plant had been entirely destroyed. Amongst the rest were two 3000-horse-power blowing-engines and a series of pumps which had been reduced to scrap.

The steelworks is in process of restoration. The building itself has been rebuilt. The open-hearth shop, with its two 40-ton furnaces and its producers, had been removed in their entirety into German works. The ironwork of the shop buildings and the producers have been recovered and reinstalled.

The rolling-mills of the Homécourt works consisted of two trains of blooming-mills of 2750 × 1100 for ingots of 4 to 5 tons, driven by steam reversing-mill engines, and a two-high reversible 850 mill of four stands, one for billets and three for large sections and rails. This mill was driven by two steam

reversing-mill engines. There were also a three-high 635-millimetre mill for smaller sections with three stands, driven by a 1500-horse-power three-phase motor, a three-high universal mill for flats up to 800 millimetres wide, driven by a 2500-horse-power motor, and a three-high Lauth mill for medium-sized plates with a three-high stand of 2200×750 millimetre rolls for smooth sheets and an 1800×700 millimetre stand of rolls for chequered plates driven by a 2500-horse-power three-phase motor, besides a large shop for the straightening and dressing of rails and sections, machine tools for making beams, and Lackawanna planing machines.

Only the mill buildings remained standing, and these badly damaged. All the plant and tools had been taken away. There were left but two bare housings in the medium plate mill and the 1500-horse-power electric motor of the medium three-high section mill, likewise badly damaged. One blooming-mill has been recovered, as well as the two 2500-horse-power motors which had been taken to a German works.

At present the mills are in course of reinstallation and work is in hand in preparation for the future reinstallation of the blooming-mill, of a Morgan billet-mill, and of a universal mill for large plates up to 1·2 metres in width.

Much of the central station electric plant, particularly two 2000-horse-power electrogenerative sets had been removed. These have been recovered and are being remounted. The other motors, which had been badly damaged, are being repaired.

Société Anonyme des Aciéries de Micheville.

At the works of this company both the steel department and the rolling-mills were utterly destroyed. Before undertaking the work of reconstruction an agreement was entered into with the Compagnie des Forges et Aciéries de la Marine et d'Homécourt that the work of the two companies should be carried on jointly, sections, rails, girders, U-sections, angles, &c., being made at Micheville, while Homécourt should specialise in sheets, plates, blooms, and billets. The Micheville works will comprise :

The six blast-furnaces which existed in 1914, renovated and altered so as to produce 250 tons of pig iron each per day.

Two gas-fired mixers of 600 tons capacity each.

A steelworks provided with four 28-ton converters, space being allowed for a fifth.

Two car-casting sets and an overhead casting crane as a standby. Space has been provided for two electric furnaces for refining purposes, to be installed later.

A battery of unfired soaking-pits with thirty-six holes and two gas-fired soaking-pits with twenty-four holes each will be installed.

The rolling-mills will consist of an 1150-metre blooming-mill driven by a steam reversing-mill engine and two steam hydraulic shears, and a 44-inch American blooming-mill driven by a reversible electric motor of 12,000 to 15,000 horse-power. These two blooming-mills will suffice to feed two semi-continuous American mills, comprising :

1. A heavy section mill consisting of one stand of 36-inch breaking down rolls, driven by a reversible electric motor of 10,000 to 12,000 horse-power; two stands of 28-inch three-high rolls driven by an electric motor of 3000 horse-power, and one stand of 28-inch finishing rolls driven by a 1500-horse-power motor. These four stands, arranged tandem at distances allowing of simultaneous rolling in each will allow of an output of 60 tons per hour.

2. A small section mill consisting of five stands of rolls arranged tandem so as to allow of the simultaneous and automatic rolling of products with an output of 40 tons per hour. This mill will be driven by two electric motors of 1500 horse-power each, and one of 500 horse-power. It will be fed from two continuous mill reheating furnaces, each capable of supplying 40 tons of blooms per hour, charging cold.

Space has been provided behind the 1150 metre blooming-mill for the installation of a continuous mill for billets and flats similar to the one to be erected at Homécourt. At the end of the mill will be installed cooling beds, live roller gear, bar banks and overhead travellers, in order rapidly to remove and deal with the mill output.

The necessary energy will be supplied by a central station containing six 6000 horse-power gas-engines (three of which are on order) generating three-phase current at 5500 volts. This power-house will be connected up with the "Sidérurgie Lorraine"

system, which connects up all the power-houses of the leading works of the region. There will also be :

1. A power-house comprising four gas-engines of 1500 horse-power each, coupled with continuous current 450 volt generators.

2. Two Rateau turbines of 1500 horse-power with 550-volt three-phase alternators, using the waste steam from the mill engines.

3. A Rateau turbine of 1500 horse-power with a 450-volt continuous current generator, using the waste steam from the reversing blooming-mill engine.

4. Two 1500 horse-power 5500-450 continuous commutators ensuring liaison between the two stations.

There will also be installed a basic shop and a slag mill corresponding with the size and needs of the works.

Space has been provided for a battery of coke-ovens capable of supplying the whole of the coke required by the blast-furnaces. The coke-oven gases will be used to heat the reheating furnaces, mixers, &c.

It will be of interest to see to what extent this programme has been put in hand.

Up to June 1921, 436,000 m.³ of foundations have been dug, 40,000 m.³ of cement put in, and 600 ferro-concrete pillars have been put in position. Nos. 1 and 2 blast-furnaces, which were partly destroyed, have been repaired ; a blast-furnace blowing-engine, taken away by the Germans, has been recovered, and a battery of boilers has been got into working conditions. A blast-furnace was blown in in March 1921. The whole of the ironwork of the former steel-melting shop and rolling-mills has had to be taken down and has been renovated and rebuilt. Over 6000 tons of ironwork have been involved in this reconstruction.

Vireux-Molhain Ironworks.

This company has also put forth great efforts, and its present state of reconstruction may be summarised as follows :

Two 20-ton fixed, open-hearth furnaces are in course of being built, as well as one 300-millimetre rolling-mill.

A tire and axle shop has been restarted, as has also a foundry. The fitting shops, boiler shops, smithies, and cylinder-boring

shops are also at work. In addition to the foregoing a 800-millimetre sheet mill, a 550-millimetre mill, a 25-ton tilting open-hearth furnace, a slag cement plant, a slag brick works, and a steel foundry are in course of construction.

Etablissements Arbel.

This company had two important centres, the Douai works in the Nord and the Couzon works in the Loire. The former have been entirely removed or destroyed. They consisted of a group of several works. The most important was devoted to the manufacture of stampings; chassis and bogies of tramcars and other rolling-stock and automobiles; boiler seatings, &c, and to structural steel work. These have been entirely rebuilt in handsome shops 308 metres long and 120 metres wide. Over 1000 tons of structural steel work is now being turned out monthly. A second works, which is at present devoted to the repair of wagons, has been fully at work for the past two years. A third works consists of the open-hearth steelworks and rolling-mills. The buildings will be completed by about the end of September; the foundations are ready and the first deliveries of plant are momentarily expected.

Finally, a fourth works will be devoted to making boilers and wagons and is in course of being built. It will cover a very large area and the machine tools ordered are actually in course of delivery. Before the end of the year it is anticipated that this works will be in regular activity. The four works provide employment for over 1200 workmen, a figure which gives some idea of the enterprise shown. A power station developing 1200 kilowatts supplies the energy to this undertaking.

The basic steel works were commenced in 1920 and the converter shop in May 1921. At present four blast-furnaces are ready as well as the power stations which contains gas-engines aggregating 1500 horse-power; four gas blowing-engines for the blast-furnaces and one for the steelworks. All the gas-engines and blowing-engines were recovered after the Armistice, from where they had been transported by the enemy. The company hopes that the steelworks and blooming-mill (which has likewise been recovered) will be ready by the end of the year, and the new rolling-mills by the end of 1922.

The Joeuf and Messempré Works of MM. de Wendel & Co.

The destruction of the Joeuf works was largely carried out by means of a heavy tup which Messrs. De Wendel have had placed on a pedestal at the works. It has been decided to restore the works at Joeuf to their pre-war condition. On the other hand, the undertakings at Messempré, which in 1914 were distributed amongst three small works, will be combined into one, between Messempré and Osnes. The reconstruction at Joeuf is in an advanced state. Four blast-furnaces have been blown in : Nos. 7 and 8 on June 11, 1919 ; No. 6 on May 27, 1920 ; and No. 5 on October 19, 1920. Two more (Nos. 1 and 4) are ready for blowing in, and Nos. 2 and 3 will be ready very shortly.

The steelworks was restarted on June 8, 1920, and the blooming-mill, which has been partly restored and temporarily completed was put to work on June 8, 1920. The wire mill, which has been entirely rebuilt, was restarted on October 25, 1920. The rail and billet mill are in course of completion and will be started almost immediately. The new three-high 600-millimetre mill is ready, while two thin sheet mills and two tinplate mills have been got to work at Messempré in April and in October 1920 respectively. The complete reconstruction of this works is under consideration.

The Works of the Société du Nord et de l'Est.

This company combines the interests of three older undertakings :

The Aciéries du Nord et de l'Est, at Valenciennes.

The Espérance works, at Louvroil.

The Société Métallurgique, at Pont-à-Vendin, Wingles.

At the outbreak of war these three works were in an advanced state of completion. At the two first the first stage of working had been reached, but not at the Pont-à-Vendin works. The repair of the more serious damage enabled, at most, the resumption of this stage at the first two works. At Pont-à-Vendin important fresh resources were needed to begin with. The carrying out of the pre-war programme in its entirety would have clashed with the interests of the component companies. On the other hand, the extent of the work of destruction was such that there was no necessity to reconstruct identically with the original

plan. For this reason it was decided to postpone until later the reconstruction of the Pont-à-Vendin works and to employ the resources thus liberated to realise the very feasible programme of the two older works at Espérance and the Nord-Est. Their reconstruction was undertaken in two stages.

The first involved the realisation of the pre-war productive capacity of the Valenciennes and Louvroil works, that is to say, three 200-ton blast-furnaces at Valenciennes and two 180-ton furnaces at Louvroil, with basic steel works and blooming and other mills capable of rolling every kind of section and of utilising the entire output of the steelworks.

The finishing mills of these two works having been destroyed as well as their buildings, this portion of the plant was redesigned in concordance with the most recent practice. All the mills being electrically driven, the company decided to enlarge the power stations. The mills comprise :

At Valenciennes : One 850-millimetre reversible mill of four stands, which is actually in existence ; one three-high 600-millimetre mill with reversing engines ; one 325-millimetre semi-continuous billeting mill and one 275-millimetre mill, served by the same billeting mill.

At Louvroil : One 350-millimetre two-high sectional mill ; one 280-millimetre two-high sectional mill and one 280-millimetre tinplate mill.

Resumption of work could only be undertaken slowly and progressively. The figures relating to the number of workmen employed gives a fair idea of the progress realised at these two works : November 1918, 89 ; March 1920, 1450 ; June 1919, 870 ; December 1920, 1900 ; April 1921, 3200. The first year's work consisted solely of digging the foundations, and actual reconstruction did not commence until 1920 at Valenciennes. It was then possible speedily to set the fitting shops to work, driven in the first instance by a gas-engine working on a lean gas. The steelworks and the railway tire and axle department were got to work in 1921. In regard to the remaining installation here and at Louvroil, which was either removed or systematically destroyed by dynamite, reconstruction, despite the energies of both workmen and staff, is far from being within sight of completion.

At the present moment two blast-furnaces out of three are

in working order at Valenciennes, together with the blowing-engines, gas cleaners, and accessories. The open-hearth plant is nearly restored, the mixer is under repair, and the blooming-mill and reversing-mill are in course of installation, while the other mills are on order. The foundations and buildings are in course of erection. The mill furnaces and the mill accessory machinery have yet to be installed. The power station is practically restored to its pre-war capacity and the additional units are on order. The overhead cranes and rolling-stock have been recovered and the works sidings and the workmen's dwellings have been put in order.

At Louvroil there only remains the brickwork of the blast-furnace mantles to be completed, the bricks being already available. The steelworks is in course of erection and the foundations for the new mixer are in. The blooming-mill proper is ready and its extension and bar bank in hand. The power station has been restored to its pre-war capacity and its enlargement arranged for. The 350-millimetre and 280-millimetre mills, as well as the 280-millimetre tinplate mill, are on order, and the buildings themselves nearly ready. The electrical machinery is also on order.

The gas-producers, the reheating furnaces, and the machine tool equipment remain to be completed.

CONCLUSIONS.

From this short account the following facts emerge :

1. The destruction of the large works in the Nord and in the eastern districts of France were not due to the war alone. The destruction was deliberate, systematic, and thorough. This applies equally to works situated along the front.

2. The reconstructional energy has been admirable and widespread, and despite financial difficulties arising out of the incomplete peace treaty, the works are, little by little, resuming their activities.

3. In the course of their reconstruction the works have been modernised. The objects of the enemy have thus been frustrated and the future industry has an outlook as prosperous and promising as that of victorious France as a whole.

DISCUSSION.

Sir HUGH BELL, Bart., Past-President, said they would desire him formally to thank Mr. Guillet for his most interesting communication. The matter was hardly one for discussion. He (Sir Hugh) had the melancholy experience of seeing the whole line from the Belgian coast to Verdun in 1919, very shortly after the German retirement. Nothing could be more striking than the extraordinary destruction which had been effected over a length of about 400 miles, with a breadth of from twenty to thirty miles. It seemed almost impossible that the effects of that destruction could ever be effaced, and it must be a great satisfaction to all of them to hear the account Mr. Guillet had been able to give them as to what had happened during the last two and a half years, of the way in which French enterprise and French courage had carried through the reconstruction of the works which suffered at the hands of the Germans. At the same time he did not know that it was very desirable that they should cast their eyes back, but rather that they should look forward. He offered on behalf of his English colleagues of the Iron and Steel Institute their most sincere condolence with their French colleagues on the losses they had sustained, and they tendered their sincere congratulations on the way in which they were seeking to repair those losses. It was in that direction that they must look for safety in the future. It was a great satisfaction to all of them to know that France had tackled the extraordinarily difficult problems confronting them.

Iron and Steel Institute.

AN EXPERIMENTAL INVESTIGATION OF THE MECHANICAL PROPERTIES OF STEELS AT HIGH TEMPERATURES.

By E. L. DUPUY (PARIS).

HISTORICAL NOTE.

LITERATURE relating to the mechanical properties of steel when hot is somewhat scanty, besides which the experiments have generally stopped short at a temperature of about 750°C ., that is to say, in the neighbourhood of, if not actually below the transformation points on heating. Only a few of these experiments will be referred to here.

Vallon (1875) records special brittleness in steel heated to blueness, and instances the following experiment. If an iron or steel rod be heated to redness, and be subjected during the cooling to bending flat a number of times, it is found that at a certain temperature, corresponding with blue heat, cracks develop on the deformed portions, whereas if bending be effected at higher or lower temperatures no flaws are produced.

Ledebur, referring to red-short metals, points out that in regard to some of them the loss in malleability only occurs within a certain temperature range, above or below which they recover their former properties.

Codron (1896) studied the load required to reduce, by slow compression, the height of iron and steel cylinders of various grades to one-half, as well as the breaking stresses and the reduction in area in the same samples. These tests were made at temperatures up to 1500°C . The temperatures were judged by the eye from the colour of the test-pieces, and must be admitted to be inaccurate within some hundreds of degrees. The curves he obtained for similar properties in different steels had the same general appearance, the hardest steel being one containing 0.6 per cent. of carbon. The breaking and crushing

loads increase somewhat towards 300° C. and then decrease, first rapidly and then more slowly, and become nil at 1500° C. The curves relating to reduction of area are more complicated, being, to begin with, horizontal, then falling towards 250° C.; showing a minimum at 375° C., and thereafter rising until, at 500° C., they reach 90 per cent. Between 1200° and 1300° they fall to zero.

Andre Le Chatelier published in 1900 an important investigation of the mechanical properties of steel at high temperatures. The experiments were made on mild rolled steels. The reduction of area which, to begin with, decreased slightly when the temperature rose, showed a sharply marked minimum at about 450° . It then increased rapidly, exhibited a bend at 900° , and again rose until, at about 1200° , it reached 95 per cent. The temperatures were very accurately measured by means of a H. Le Chatelier thermocouple, but the points taken experimentally in the region of the critical temperatures being few in number only show the general trend of the phenomena.

Brinell (1905) investigated the ball hardness of two steels containing 0.17 per cent. of carbon at different temperatures. The curves revealed an increase in hardness at 250° C., followed, from 500° upwards, by a decrease, which to begin with was rapid but became slower.

Robin (1908) found similar results when measuring the hardness of steels of varying grades.

Guillet and Revillon (1909) gave impact resistance values for various steels at temperatures between the normal and 600° . The various curves, after giving a slight maximum at about 180° C., showed a bend up to 500° C. and then rose rapidly.

From these various investigations it is, in short, only possible to gather that between about 300° and 400° C. steel displays a blue-heat brittleness characterised by an increase in the tensile strength and a well-marked reduction in area, followed by a uniform diminution in the tensile strength and an increase in the reduction of area. The latter reaches from 95 to 100 per cent. at between 1000° and 1300° C. On the other hand, the passage through the transformation points is not attended with any special anomaly.

Rosenhain and Humphrey (1913) carried out an exceedingly

careful series of experiments, with the object of ascertaining the influence of the transformation points on the tensile strength and on the mode of fracture. They employed sheets of electrolytic iron, or of dead soft steel containing 0.1 per cent. of carbon. The section across the fracture was about 1 by 3.18 millimetres. To obviate oxidation the furnace and test-pieces were placed *in vacuo*. The observations were taken on a cooling temperature curve, the test-pieces being heated to 1100° C. and then cooled to the temperature required. Only the breaking stresses were recorded. The elongations yielded irregular results, and the reductions of area were not measured. The resulting temperature-breaking-stress curve displayed two clearly marked discontinuities, and a third, which was doubtful. The two former discontinuities corresponded respectively with the points Ar1 and Ar2 of the metal under investigation, but the third occurred at about 30° higher than Ar3.

As will be shown in the conclusions arrived at in the present investigation, the author is not quite in agreement with Rosenhain and Humphrey in regard to the correspondence between the anomalies and the critical points of the metal. Quite recently, and when the present investigation was almost completed, the author heard of a memoir presented by Mr. Gouvy before the Society of Civil Engineers of France, giving certain details relative to the manufacture and properties of Armco iron. This metal, which is neither more nor less than extra pure steel containing less than 0.02 per cent. of carbon, displays the peculiarity of not being capable of being forged or rolled between 850° and 990° without cracking. It possesses, within this range, a degree of brittleness which renders any working impossible.

EXPERIMENTAL ARRANGEMENTS.

The investigations summarised in the present research had as their object the determination of the mechanical properties of steels in respect of their carbon percentages, at all temperatures between the normal and incipient fusion. Further, in order to ascertain what might be the influence of the size and orientation of the grains on these properties, experiments were carried out upon both cast and rolled material.

Steels Employed.—Five grades of open-hearth steels were selected, the analyses being shown in the table below :

Mark.	Carbon.	Manganese.	Silicon.	Phosphorus.	Sulphur.
29	0·15	0·46	0·06	0·014	0·034
61	0·44	0·63	0·15	0·005	0·020
27	0·55	0·70	0·52	0·014	0·023
45	0·92	0·44	0·24	0·019	0·027
57	1·23	0·35	0·25	0·014	0·025

Test-Bars.—From each of the casts selected two square ingots, 1 metre long and 320 by 320 millimetres in section, were chosen, from one of which the unworked bars were taken, while from the other bars were cut after rolling.

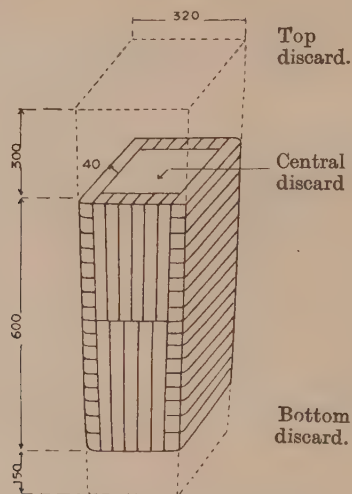


FIG. 1.—Method of Cutting the Bars.

Bars Cut from the Ingot.—The test-bars were sawn cold from the air-cooled ingot, and underwent no heat treatment of any kind. In order to ensure the metal being sound, free from piping, and capable of yielding bars crystallographically identical, vertical slices, 40 millimetres thick, A, B, C, D, were cut, after discarding 30 per cent. from the top of the ingot, parallel with the sides (Fig. 1).

These slices were subsequently sawn into pieces 30 millimetres thick, from which the test-bars were turned. Centering on the lathe was effected in such manner that the centre of the section in which fracture would occur was within 30 millimetres of the sides of the original ingot (Fig. 2, Plate I.). It resulted from this method of cutting the bars that their centre axes were either parallel with, or at right angles to, the axis of the ingot. Comparative tests showed that the mechanical properties were the same in either case.

Rolled Bars.—The ingot selected for furnishing the rolled bars was first cogged down to square billets 105 by 105 millimetres,

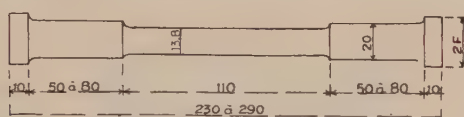


FIG. 3.—Test-piece. Normal type.

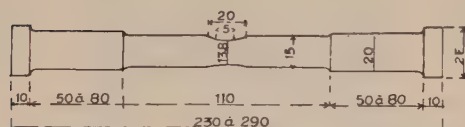


FIG. 4.—Test-piece with contracted Fracture Zone.

which, after cooling, were reheated and re-rolled to rounds having a diameter of 27 millimetres.

Dimensions of the Bars.—The section for fracture selected was one of 150 square millimetres, corresponding with a diameter of 13.8 millimetres. Figs. 3 and 4 give their dimensions. They were made by turning the bars down to a diameter of 14 millimetres and finishing on an emery-wheel with an abundant water supply to obviate heating. In some instances it was necessary to employ bars in which a crack had already developed. In such cases the bars were 16 millimetres in diameter, with a centre portion further reduced, for a length of 5 millimetres, to 13.8 millimetres, and shouldered off at each end (Fig. 4).

Treated Bars.—The treatment for the whole series of tests consisted of placing the bars in a cold furnace and heating them up over a period of $1\frac{1}{2}$ hours to 925° C. The temperature of

heat treatment once attained was kept constant for ten minutes in order to ensure uniformity of temperature between the centre and the surface of the bars. This annealing was followed by cooling in still air. The treatment was carried out on worked bars 16 millimetres in diameter, the reduction to the final dimensions being made after the heat treatment.

METHOD OF TESTING.

The tests were carried out on a 50-ton loaded-beam Falcot machine, the reading of the load being taken on a mercury

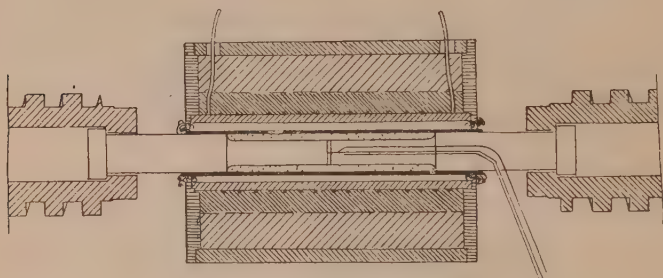


FIG. 5.—Platinum Resistance Furnace.

manometer, which allowed for the readings being within about 25 kilogrammes, that is to say, in the case of bars 150 square millimetres in section to within about 200 grammes per square millimetre. The error involved would therefore be less than that arising from irregularities in the bars themselves.

In this type of machine the test is effected at a constant rate of elongation. The author carried out the tests uniformly at a rate of 12 millimetres elongation per minute. The machine is driven by an electric motor, which enables it to work without either shock or recoil.

Heating Arrangements.—Two different sets of arrangements were employed for the heating according as the tests were to be effected above or below 1250°C .

Tests made below 1250°C .—The bar was placed in the axis of a platinum tube-resistance furnace 160 millimetres in length and 32 millimetres in interior diameter (Fig. 5). The metal is

protected from oxidation by sheathing the 13·8 millimetres diameter portion in sheet metal resting on the projecting shoulder of the test-piece. The intervening portion was packed either with steel filings or with wood charcoal. Comparative tests showed that both modes of protecting the bars gave identical results from the point of view of the mechanical properties on heating.

Tests above 1250° C.—In the tests carried out at very high temperatures the platinum resistance furnace was replaced by another furnace of the same dimensions, but in which the heating portion consisted of a carbon tube subjected to a current about

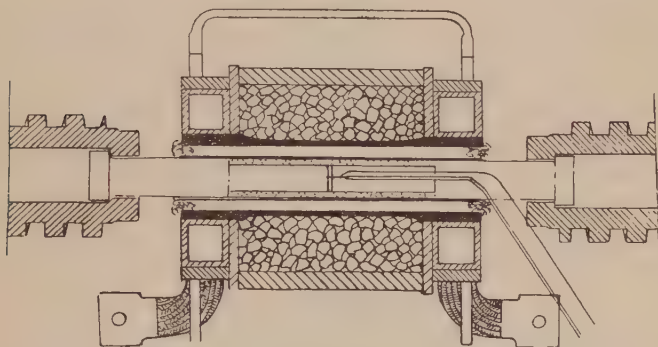


FIG. 6.—Carbon Resistance Furnace.

400 amperes at 12 volts (Fig. 6). An arrangement of rings cooled by flowing water protected the ends of the test-pieces from being overheated. In these tests the bars were always placed in mild steel filings in order to avoid the formation of a cement-iron skin, due to the action of the carbon protecting sheath.

Measurement of the Temperatures.—The hot junction of a platinum-platinum-rhodium Le Chatelier pyrometer was fixed by means of a $\frac{1}{2}$ millimetre nichrome wire, so as to be in contact with the central portion of the bar. The electromotive force read by means of a millivoltmeter enabled the temperature of the thermocouple, and therefore the control of the heating, to be regulated within about 2°. The thermocouples were calibrated by taking as fixed points the boiling of naphthalene (219°), boiling

sulphur (445°), and the melting of copper (1088°), and by calculating from these values the coefficients of the formula :

$$V = a + bt + ct^2.$$

The couples were invariably restandardised twice a week, hence no divergence over 0.05 millivolt ever occurred at the 1088° point.

Heating the Bars.—The regulation of the heating was always carried out in such a manner as to attain the required temperature at the rate of 20° per minute. Heating was carried up to a temperature 10° higher than that which it was desired to attain, and five minutes were taken in cooling down to the final temperature selected. This method of operating secured the equalisation of the temperature throughout the whole fracture-section of the bar. Every endeavour was taken to make the method of operating as systematic as possible, so that errors due to such causes as unequal heating, discrepancies between the temperature of the thermocouple and that of the centre of the bars, &c., were constant. The results obtained may, so far as their absolute values are concerned, be subject to slight allowances, but they are none the less comparative.

EXPERIMENTAL RESULTS.

Steel containing 0.15 per Cent. of Carbon. (Figs. 8 and 9.)

1. *Steel as Cast.*—The breaking stress in the cold was 34 kilogrammes per square millimetre. It remains practically constant up to about 500° , although showing a slight maximum at about 250° . It then diminishes uniformly up to 750° , at which temperature breaking occurs under a stress of 9 kilogrammes.

Above this point the curve exhibits a slight degree of discontinuity. It falls, but increasingly slowly, until it reaches 825° C. The first sample tested above this temperature—that is to say, at 900° —did not break through the middle, but showed two contractions equi-distant from the middle of the bar, and at one of which fracture took place (Fig. 7, Plate I.). As, owing to the arrangement of the furnace, the middle of the bar would be hotter than the extremities, this anomaly appears to show that the breaking stress traverses a minimum and subsequently rises. Instead, therefore, of the bars hitherto employed, a bar of the

type narrowed down for 5 millimetres was used in order to influence fracture in this region, the temperature of which was measurable. In this case a test carried out at 775° showed a

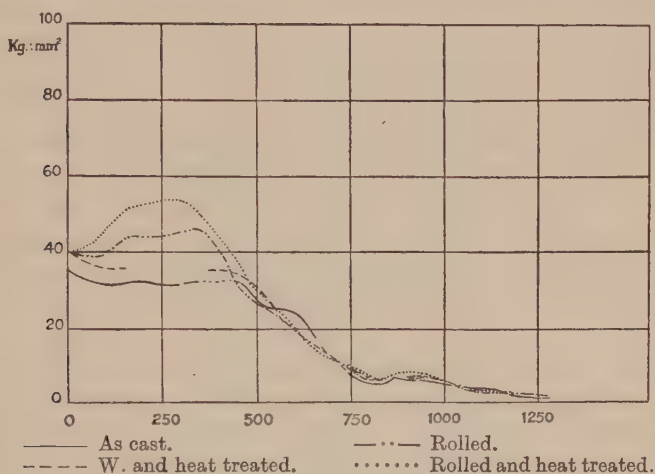


FIG. 8.—Carbon, 0.15 per cent.

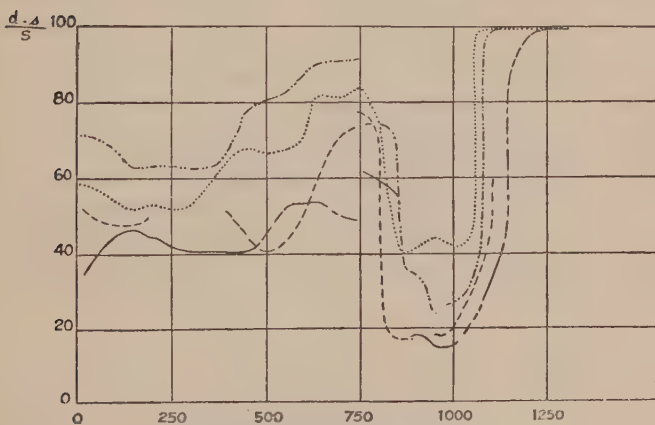


FIG. 9.—Carbon, 0.15 per cent.

breaking stress of 6 kilogrammes per square millimetre. This U-shaped curve continued up to 870° , the temperature above which the load began to decrease.

The contraction at 16° was 35 per cent. At 200° and at 600° it presents maxima, followed by slight stepping, and at 750° it

reaches 48 per cent. At this point a discontinuity occurs and it rises to 54 per cent. It falls rapidly thereafter to 14 per cent. at 950° , and then increases afresh and reaches 100 per cent. at 1200° .

These variations in two measurable quantities, breaking stress and reduction of area, are accompanied, as will be seen later, by variations in the appearance of the fractures.

2. *Metal as Cast and Heat Treated.*—Annealing at 925° followed by air-cooling slightly modifies the mechanical properties of the metal, while preserving the same general characteristics. An examination of the curves shows that the breaking stress in the cold increases by 6 kilogrammes per square millimetre, this difference diminishing gradually in proportion as the temperature rises.

The reduction is similarly increased to a notable extent. The improvement is particularly noticeable between 600° and 750° .

3. *Rolled Metal.*—The very heavy working which the metal had undergone during rolling (a reduction of 100 to 1) had very little influence on the breaking stress, and the curves all preserve the same general characteristics. Reduction of area is, on the contrary, markedly increased; it reaches 100 per cent. in the neighbourhood of 150° , that is, at a lower temperature than the cast metal, and remains constant up to 1400° . It then falls suddenly to zero simultaneously with the breaking stress.

4. *Rolled Metal Heat-Treated.*—The influence of annealing is particularly marked below 750° . Within this range the reduction of area which falls from 71 per cent. to 62 per cent. between 150° and 350° (blue brittleness) rises thereafter, and at 750° reaches 91 per cent.

Steel containing 0.44 per Cent. of Carbon. (Figs. 12 and 13.)

Steel containing 0.44 per cent. of carbon behaves very similarly to dead soft steel. Up to about 750° the steel, as cast, breaks almost without contraction. Annealing improves the contraction at low temperatures, raising it from 12 or 15 per cent. to 20 per cent., but its influence is more particularly marked at 450° and upwards, a temperature at which the malleability of the metal begins to increase and eventually reaches 70 per cent. at 750° .

Rolling further increases this ductility, and after showing a minimum at about 300° the contraction increases rapidly between 350° and 400° , and then more slowly, ultimately reaching 65 per

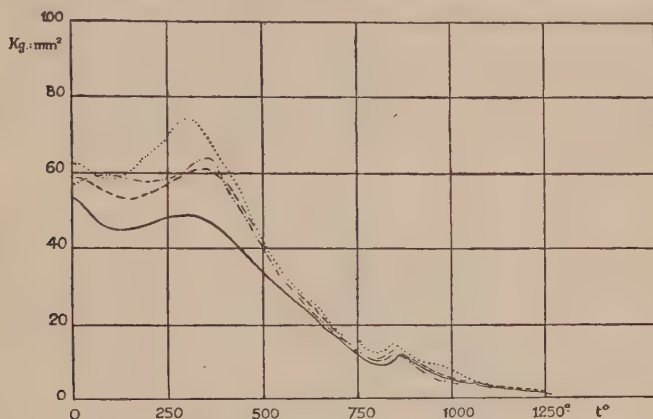


FIG. 12.—Carbon, 0.44 per cent.

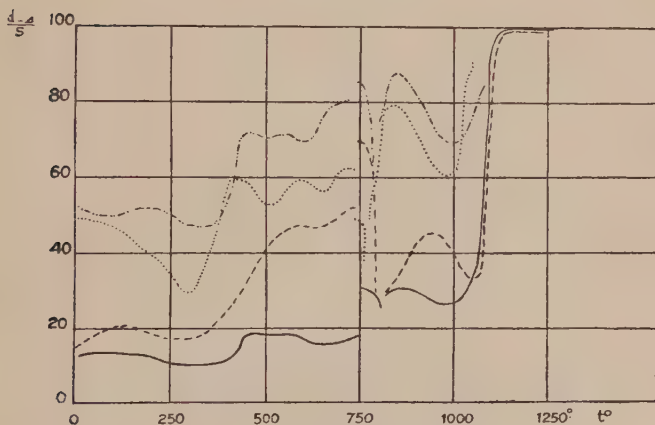


FIG. 13.—Carbon, 0.44 per cent.

cent. at 750° for the untreated rolled metal and 85 per cent. for the heat-treated rolled metal.

The breaking stress decreases slowly to begin with when the temperature rises, shows a minimum between 120° and 150° ; then rises up to 300° , and thereafter diminishes uniformly up to

750°. The curves corresponding with the breaking stresses under the different conditions are parallel with each other.

At 750° the two series of curves show a discontinuity. The reduction of area undergoes a sudden increase followed by a diminution. It then rises, and after again falling at about 1000°, increases rapidly until it reaches 100 per cent. at 1100°. The breaking stress shows a minimum at 610°, rises thereafter up to 850°, and falls uniformly until fusion point is reached.

Steel containing 0.55 per Cent. of Carbon. (Figs. 23 and 24.)

The curves showing the variations in the mechanical properties of steel containing 0.55 per cent. of carbon, divide themselves below 775° up to 800° into two groups. These groups correspond, on the one hand, with the metal as cast, and on the other with the metal as heat treated or rolled.

The steel as cast breaks below 800° with a very small reduction in area. From this point there is a sudden improvement, the reduction in area increases from 7 to 45 per cent., and remains in this neighbourhood up to about 1000°, and becomes 39 per cent. at 1125°. Towards 1400° it suddenly falls to nil. The breaking stress, which commences at 66 kilogrammes per square millimetre, falls at first, but recovers a little later and becomes 65 kilogrammes at 360°. It then falls, at first, slightly, and then more rapidly above 550°. At 800° it exhibits a discontinuity. The fracture alters its appearance at this temperature; whereas below 800° it occurs, owing to a parting between the pearlite grains; above that temperature a new structure is seen (Fig. 17). The curve takes a U-form until it reaches 940°. Above this temperature it again forms uniformly to about 1400°, at which it suddenly falls from 1.3 kilogramme per square millimetre to nil. In regard to the second group, the reduction of area remains in the vicinity of 25 to 30 per cent. at 375°. It then rises rather rapidly and exhibits a step between 400° and 500°, falls to a minimum at 600°, and continues with some oscillations up to 775°, when it exhibits a discontinuity. The diminution in the area increases suddenly and then falls at 900°. It again rises, and at 980° reaches 99 per cent.

The breaking stress after showing a slight minimum at 175°

risks up to 310° . After that maximum it falls uniformly up to 800° , when there is a slight discontinuity followed by a few oscillations, and uniform diminution commences above 940° .

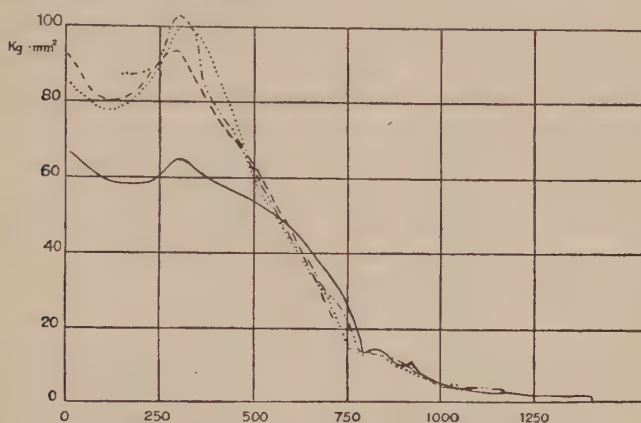


FIG. 23.—Carbon, 0.55 per cent.

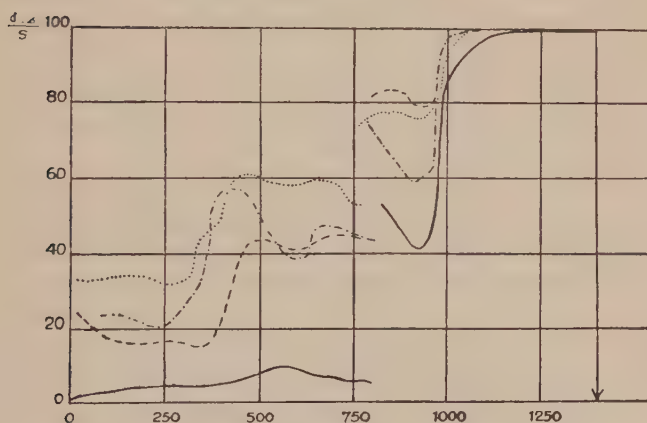


FIG. 24.—Carbon, 0.55 per cent.

The micrographic examination affords a reason for the causes of this difference between the steel as cast and as heat treated. It shows that in the cast steel the structure is almost wholly pearlitic with crystallites of thin streaks of ferrite in the joints. The structure is therefore abnormal, showing that the apparent

carbon content is in the neighbourhood of that corresponding with the eutectic. The fracture as shown in the photos of test-pieces before and after fracture occurs in the ferrite of the joints without the pearlite areas being markedly deformed. As these joints are extremely thin their deformation does not appreciably modify the section of the sample after fracture. On the other hand, after heat treatment and, *a fortiori*, after rolling, the excess of ferrite is expelled from the pearlite, thus allowing a far greater reduction in area in proportion to the actual percentage of carbon.

Once the A1 point has been passed the appearance of austenite makes the structure of the cast metal resemble more closely that of the heat-treated metal. Hence the similarity of the curves above 775° (Figs. 18-22).

Steel containing 0.91 per Cent. of Carbon. (Figs. 25 and 26.)

This composition corresponds with that of the eutectoid steel up to 450°, and whether the test-pieces cut from the ingot were heat treated or not fracture takes place owing to brittleness and occurs between the crystallite (Figs. 25 and 26). From 450° to 800° the breaking stress of the metal as cast falls from 70 to 9 kilogrammes per square millimetre. The reduction of area within this range increases slowly from 4.5 to 8.6 per cent. At this point the malleability increases suddenly and reaches 98 per cent. at 850°, and 100 per cent. shortly after. The breaking stress thereafter decreases more slowly until it reaches 17 kilogrammes per square millimetre at 1150°. The representative curve thus consists of two branches intersecting each other at 800°.

Heat treatment does not appreciably increase the tensile strength. The reduction of area, on the other hand, is markedly modified in the region below 800°. Starting with 43 per cent. at 400° the curve falls, to begin with, to 33 per cent. at 600°, and then rapidly rises to 99 per cent. at 800°.

The properties of the rolled metal are closely similar whether it has been heat treated or not. The breaking stress first rises up to about 325°, where it reaches 113 kilogrammes per square millimetre in the untreated metal, and 118 kilogrammes per square centimetre in the heat-treated metal. It falls subsequently up to 800°, at which point the curves coalesce. At still higher

temperatures the breaking stresses are practically independent of the amount of working or of the heat treatment of the metal.

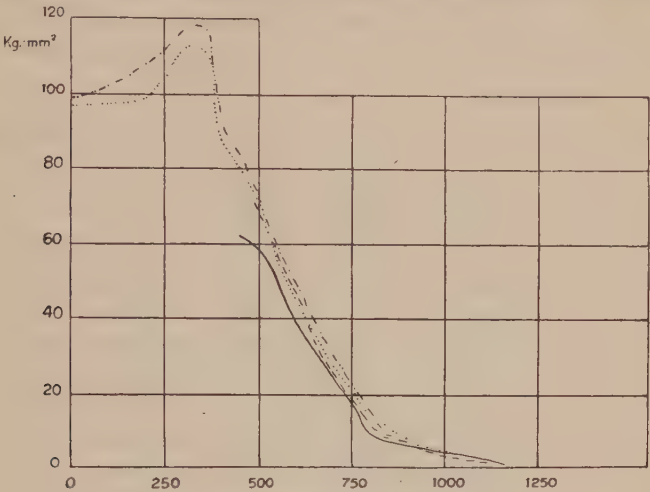


FIG. 25.—Carbon, 0.91 per cent.

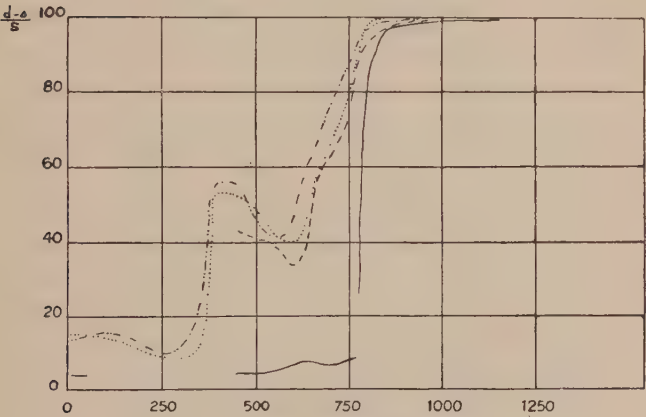


FIG. 26.—Carbon, 0.91 per cent.

The two curves relating to reduction in area behave similarly; that of the heat-treated metal being slightly higher than that of the untreated rolled metal. On the temperature being increased the reduction in area diminishes slightly from 14 to 16 per cent. down to 10 per cent. at 325°. The curve then rises almost

vertically, and exhibits a maximum of 55 per cent. at 400° , after which it falls slightly down to 40 per cent. at 575° , and then rises rapidly until it reaches 99 per cent. at about 800° , and 100 per cent. soon afterwards. It then falls to nil at 350° .

Steel containing 1.25 per Cent. of Carbon. (Figs. 27 and 28.)

Cast steel containing 1.25 per cent. of carbon is exceedingly brittle in the cold. In certain bars fracture occurs in the heads of the test-pieces, which are 25 millimetres in diameter, without the body of the test-pieces, which are 13.8 millimetres in diameter, having undergone any appreciable deformation. Uniform fractures do not begin to occur after 500° has been reached.

The breaking stress starting at 100 kilogrammes per square millimetre for heat-treated cast metal, and at 106 kilogrammes per square millimetre for rolled and heat-treated metal, rises rapidly up to about 300° , at which temperature it reaches 110 kilogrammes per square millimetre in the case of the heat-treated cast metal, and 130 kilogrammes per square millimetre for the heat-treated rolled metals. It then falls uniformly to about 18 kilogrammes per square millimetre at 760° . At this temperature the curve exhibits a very slight discontinuity, followed by a few slight oscillations. It falls slowly thereafter up to 1350° , where it suddenly drops from 3 kilogrammes per square millimetre to nil.

The curves relating to the reduction in area possess more character. In regard to the metal as cast, the curve of the reduction of area starts from nil at 490° . It rises with a few oscillations up to 775° , at which temperature it amounts to 7.5 per cent. It then remains in the neighbourhood of 15 per cent. up to 875° , when after a slight oscillation it rises to 99 per cent. at about 1200° . In the case of the heat-treated or rolled steel the reduction in area, which in the cold is about 5 per cent., rises to 20 per cent. between 300° and 450° , and remains in the neighbourhood of this amount up to 775° , oscillating a little at 600° . From 775° it rises suddenly, remains at about 45 per cent. up to 875° (or 30 per cent. in the case of the heat-treated cast steel), and then begins to increase until it reaches 99 per cent. at about 1000° . At 1356° it suddenly falls to nil.

If the whole of the results relating to various grades of steel be examined, it will be seen that when the temperature increases

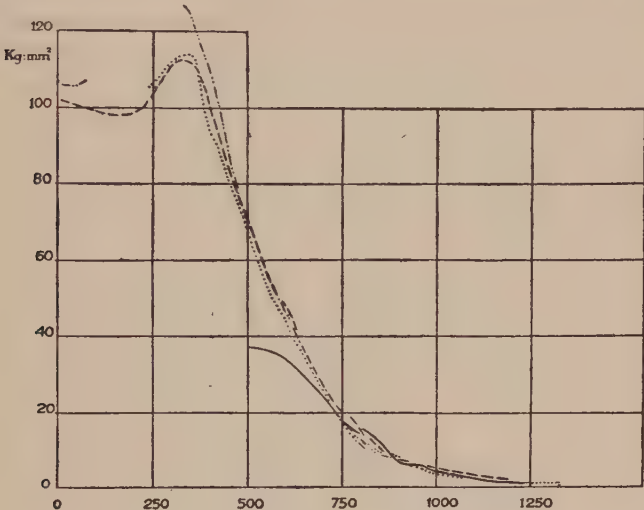


FIG. 27.—Carbon, 1.25 per cent.

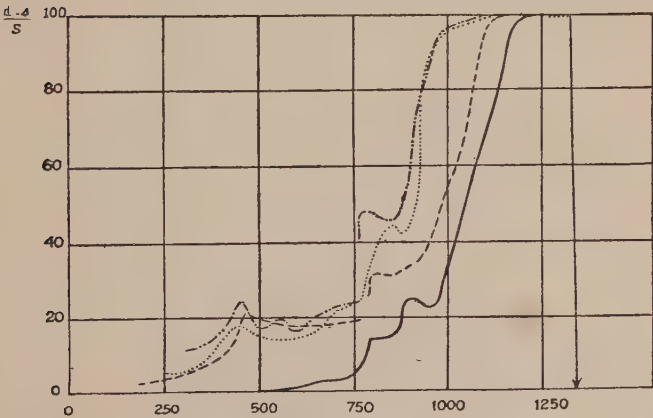


FIG. 28.—Carbon, 1.25 per cent.

the breaking stress to begin with undergoes a slight decrease. After this it rises, showing a maximum at about 300°—that is to say, in the vicinity of blue heat. From this point there is

a uniform decrease, with perhaps a slightly marked anomaly in the neighbourhood of 450° to 550° , this uniformity continuing up to just below 750° . A discontinuity then occurs, followed to begin with, in hypo-eutectoid steels, by a slight lowering in the breaking stress, and then an increase, giving a representative and characteristic U-shaped curve, whereupon, after a slight flattening, the breaking stress begins to fall until the commencement of the liquidus, where it suddenly falls to zero. In the case of eutectoid steels, the U-shaped branch does not occur, while in hypo-eutectoid steels it is superseded by a curve showing a bend at about 875° .

These different anomalies are even more marked in the case of the curves relating to reduction of area. There is, to begin with, a slight fall in the reduction of area, a minimum at about 300° , corresponding with the maximum in the curves relating to tensile strength. There then occurs at about 450° a rapid increase, which is the more marked in proportion as the metal contains less ferrite. After a slight step, the reduction in area diminishes slightly, and then increases up to 775° . From this point the various grades of steel behave differently, according to their percentage of carbon. In the case of dead mild steel, after a well-marked increase the curve of the reduction of area falls rapidly up to about 875° . It then shows certain oscillations; attains 100 per cent. in the vicinity of 1050° , and ultimately falls to zero simultaneously with the breaking stress. The minimum in the neighbourhood of 900° is the more marked in proportion as the percentage of carbon is higher, and in the case of the eutectoid steel the curve relating to the reduction of area begins to rise from 600° onwards, and attains 100 per cent. at about 760° . In the case of steel containing 1.25 per cent. of carbon there occurs once again a branch of the curve, which is almost horizontal and constitutes the step between the regions of low reduction (at temperatures below 760°) and those at which they reach 100 per cent. In order to summarise these results, the author has constructed a diagram for the metal as cast (surface—reduction in area—carbon percentage—temperature), Fig. 31. The three-dimensioned figure thus obtained affords an easier method of taking into account the mode in which these properties vary in respect of the two other variables.

To what extent can these results be made to harmonise with the existing diagram of the iron-carbon alloys?

There is seen to begin with, and in regard to all the grades of steel under investigation, an initial anomaly at about 750° . This temperature is in the neighbourhood of that corresponding with the A_{c1} point for rates of heating of the order of those attempted in the author's experiments. It is known, further, that in the case of the steel containing 0.9 per cent. of carbon—that is to say, not presenting any transformation point—this anomaly is the only one observable. An examination of the dead mild steel test-pieces shows, too, that above this temperature the steel still contains ferrite. In the cold, as has been seen, tensile stress begins by deforming the ferrite grains, which become elongated in the direction of the stress; in the case of the steel as cast wherein the grain structure is unusually coarse, the bar, which to begin with exhibits a brightly polished surface, assumes a characteristic roughened appearance. Now, when the breaking temperature at which this appearance ceases to be exhibited is investigated, it will be seen that it is not until 860° has been reached that the specific mode of ferrite deformation ceases to be observed. The anomaly at 750° evidently corresponds, therefore, with the disappearance of the pearlite, which is transformed into austenite with 0.9 per cent. of carbon, that is to say, at the A_1 point (Fig. 32).

Dead soft steels show, between 750° and 860° , fresh modifications in their properties, but contrary to what occurs at the A_1 point, the transition takes place progressively. Now, as has already been seen, it is at the latter temperature that an alteration in the exterior appearance of the bars is observed. The roughened effect disappears suddenly at 860° . The appearance of this variation presents close analogy with that of magnetism, which diminishes gradually within the same interval, that is, up to the A_2 point. It would appear, therefore, that there is some correspondence between this variation and the transformation point.

Above A_{c2} the appearance of a broken test-piece is no longer the same: fracture occurs to some extent by separation between the grains, and almost without deformation, the metal yielding almost like a piece of dry indiarubber. This phenomenon, which

is specially marked in the case of dead mild steels, becomes gradually less marked in proportion as the percentage of carbon increases.

Steel with 0.55 per cent. of carbon no longer exhibits this variation in properties corresponding with the Ac2 point. The fracture at above 760° exhibits by stages a transition from a smooth appearance to a crinkly appearance (Fig. 33, bars 1, 2, and 3). How can this variation in the mode of deformation before fracture be explained? It is necessary to remember that it is a question, here, of a heterogeneous material. At above the Ac1 point hypo-eutectoid steels consist of grains of ferrite in the α or β state (the author only uses the latter term in order to designate the condition of the metal between the two lines A2 and A3 in the diagram, without assigning to it any signification in regard to the allotropic state) embedded in a network of austenite derived from the transformation of the pearlite. When structures, the plasticity and rigidity of which differ, are in juxtaposition with each other, the mechanical properties observed, unless these elements are intimately commingled, are those of the least rigid constituents. As will be seen in the sequel, austenite is distinctly plastic. In admixture with ferrite, either transformed or untransformed, but presenting a higher degree of mechanical resistance, it will play the part of a deformable binding medium, similar to the basic constituents of an anti-friction metal.

When the carbon is very low (steel with 0.15 per cent. of carbon) the austenite network contains discontinuities, and the mechanical properties are intermediate between those of the two constituents. As the tensile strength of those constituents differs somewhat, the ferrite undergoes an initial deformation before rupture takes place. An examination of the diagrams shows that in the region comprised between A1 and A2 or A3 the breaking stress does not vary greatly in respect of the percentage of carbon, the contraction of area having similar values of the same order in all test-pieces which have undergone similar heat treatments.

The region A2 to A3 is characterised by a rise in the breaking stress, and the metal breaks almost without deformation. If it be allowed that in the β state ferrite has a higher range of

flow than it has below Ac_2 , it would result that fracture would take place in the joints of the austenite, before the ferrite had begun to undergo deformation. In regard to dead soft steel, owing to the minute dimensions of the plastic joints, fracture would occur without appreciable deformation in the metal, that is to say, with a very low degree of contraction of area. It is with this zone that the region of brittleness noticed in forging the metal corresponds.

At high temperatures the breaking stress is very low; the metal is wholly plastic, and the broken test-pieces exhibit a sharp needle-shaped point, corresponding with a contraction of area equal to 100 per cent. This region corresponds with that of the austenite. It is only below a temperature in the neighbourhood of the Ac point that this plasticity decreases. Steel containing 1.25 per cent. of carbon does not exhibit a direct transition of its mechanical properties from those corresponding with pearlitic contraction to the plasticity corresponding with the austenitic region. This is because, as a matter of fact, such a metal contains an excess of cementite, which still remains stable at above A_1 , 2, and 3. The plastic state only corresponds with the total solution of the latter, that is to say, at the point A_{cm} .

Finally, the intervention of the liquidus, which deprives the steel of all its consistency, causes it to break without deformation under an infinitely small load, similar to the case of wet sand.

CONCLUSIONS.

The author has, to begin with, taken, in regard to this investigation, the values of the breaking stress and contraction of area as characteristic of the mechanical properties at various temperatures. The results obtained appear to show that the mechanism of fracture is not the same at different temperatures.

The figures obtained cannot therefore be taken as invariable measures of the same phenomenon: it is necessary to regard the curve representing the breaking load or the contraction of area not as a single curve exhibiting a certain number of singularities, but as a series of different curves, plotted one with another on the same diagram. The observed phenomena are therefore

fairly complex, for besides the temperature and the composition it is necessary to take into consideration the nature and physical structure of the elements constituting the aggregate. To sum up, steels can be divided as follows :

1. Below A1 (and having A2 as their limit) :

Dead soft steel : ferrite which undergoes deformation by cleavage before fracture.

Hypo-eutectic steels : only the ferrite undergoes appreciable deformation ; fracture takes place when the pearlite areas come into contact with each other.

Eutectic steels : fracture almost without any deformation.

Hyper-eutectic steels : brittleness due to the presence of cementite.

2. Austenitic region :

No matter what the carbon percentage is, the γ -iron is entirely plastic.

3. Region comprised between A1 and A2 :

The plasticity increases with the proportion of γ -iron.

4. Region comprised between A2 and A3 :

Fracture almost without deformation owing to the low proportion of γ -iron and the brittleness of iron in the β region.

5. Intervention of the liquidus :

Sudden and simultaneous fall in the breaking stress and the plasticity.

The above investigations were carried out during January-September 1920, at the Compagnie des Forges de Chatillon Commentry et Neuves-Maisons at Montluçon, under the superintendence of Mr. Girard, head of the Testing and Metallurgical Research Department. The author's thanks are due to him for the facilities placed at his disposal for carrying out the work, and he also wishes to place on record his gratitude to Professor H. Le Chatelier, whose valuable advice has been of the greatest assistance.



FIG. 2. Steel with 0.44% Carbon as cast. Macrograph showing how test piece was cut from bar ($\frac{1}{2}$ natural size).

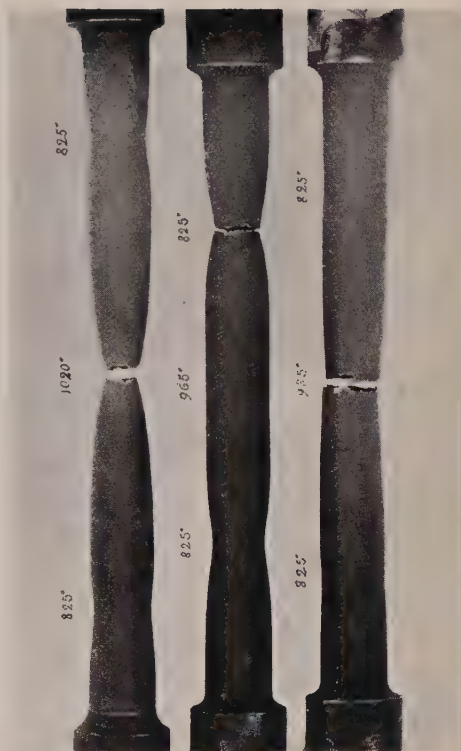


FIG. 7. Steel with 0.15% Carbon. Rolled.

Steel containing 0.15% of Carbon.

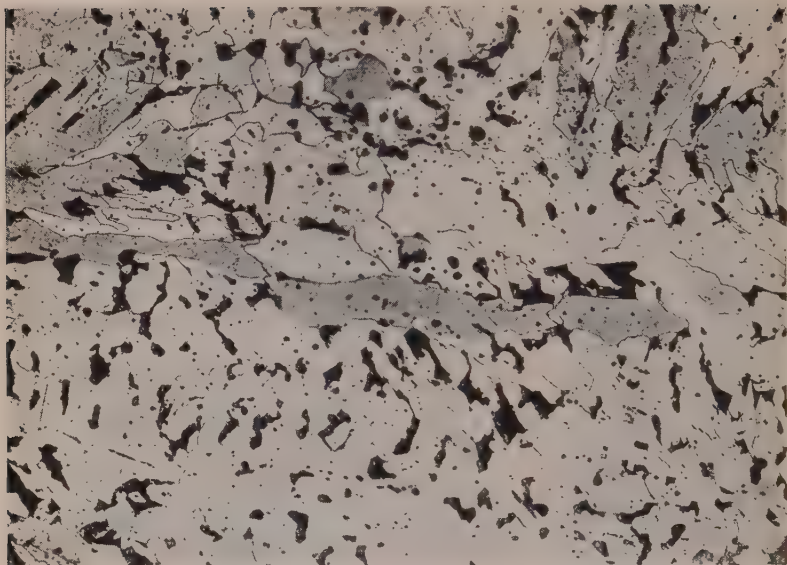


FIG. 10. As cast ; along the long axis of test bar. $\times 35$.
Etched with nitric acid in alcohol.



FIG. 11. The same after heat treatment.

Steel containing 0.44% of Carbon.



FIG. 14. As cast. Section at right angles to longitudinal axis of bar. $\times 37$.



FIG. 15. Section along longitudinal axis of bar.
 $\times 37$.

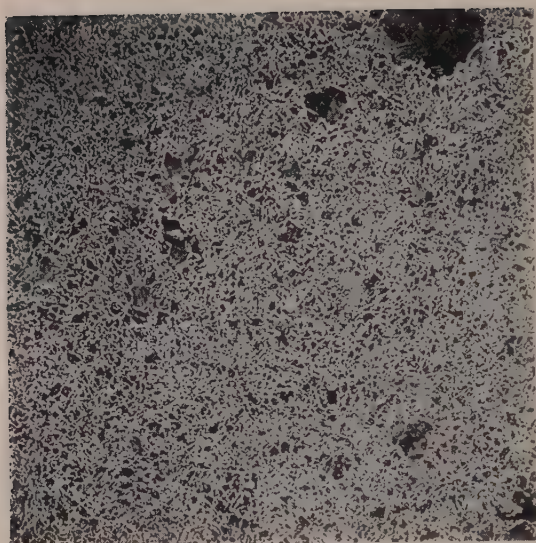


FIG. 16. Same as Plate III, Figs. 14 and 15.
Heat treated. $\times 37$.

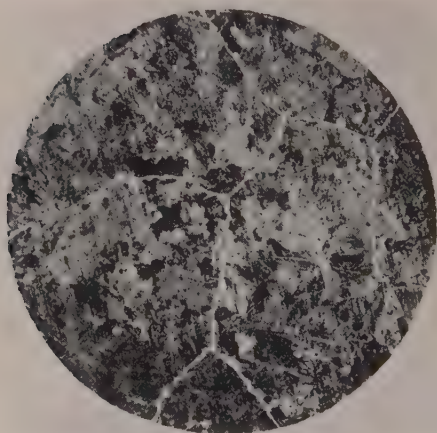


FIG. 19. Same as Fig. 18, but across axis.
 $\times 37$ and reproduced full size.

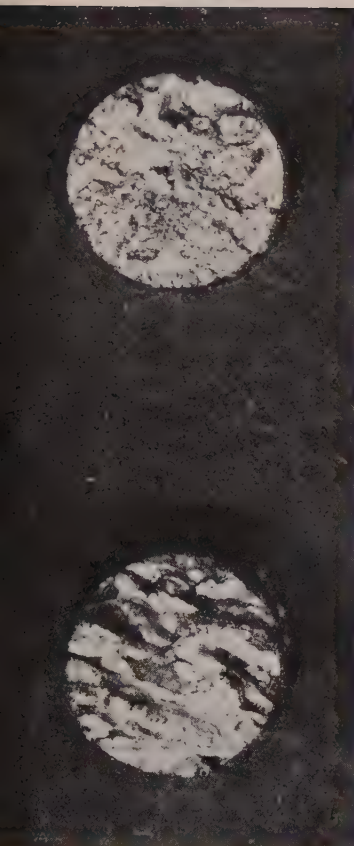
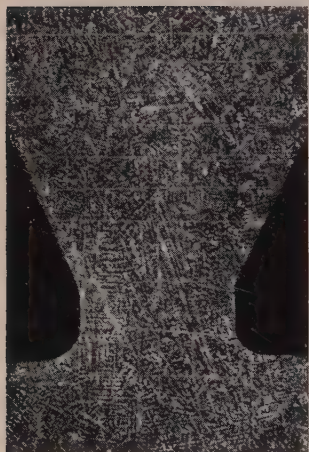


FIG. 17. Steel containing 0.55% of Carbon, as cast at 725° and 785° respectively. $\times 2$.



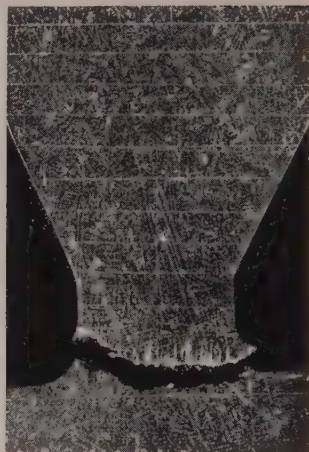
FIG. 18. Same Steel, showing zone of fracture across plane perpendicular with axis of test piece. $\times 37$ and reduced $\frac{1}{8}$ size.

Steel containing 0.55% of Carbon, as cast. $\times 2$.



(a)

FIG. 20. Before Fracture.



(a)

FIG. 21. After Fracture.

(a) Etched with nitric acid in alcohol. (b) Etched with cuprous reagent.

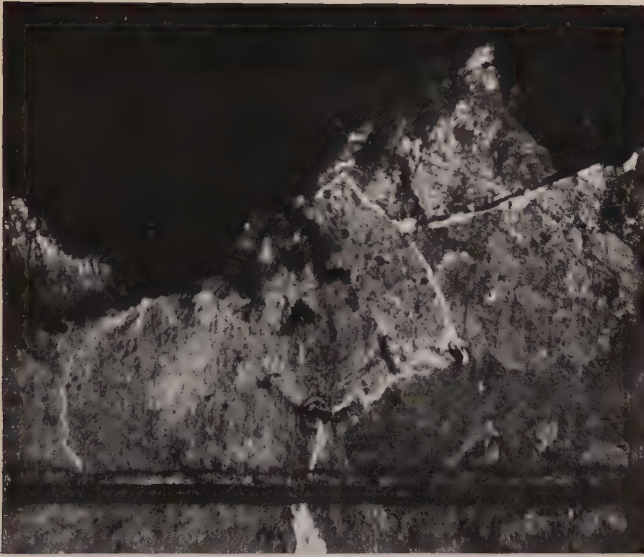


FIG. 22. Fracture of 0.55% Carbon Steel passing through a Ferrite Junction. $\times 40$. See Figs. 20 and 21, Plate VI.

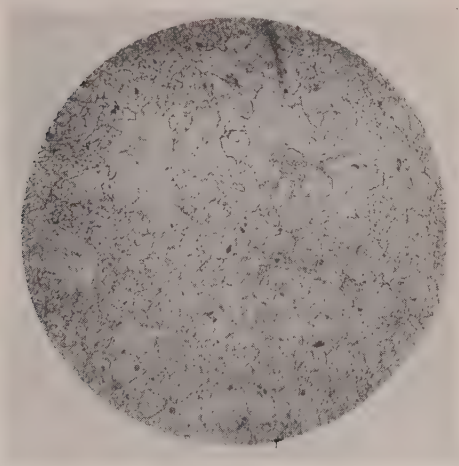


FIG. 30. Same as Fig. 29, heat treated and etched with picrate of soda.

Steel with 1.25% of Carbon, as cast.



FIG. 29. Section at right angles to the longitudinal axis of test bar, etched with nitric acid in alcohol.

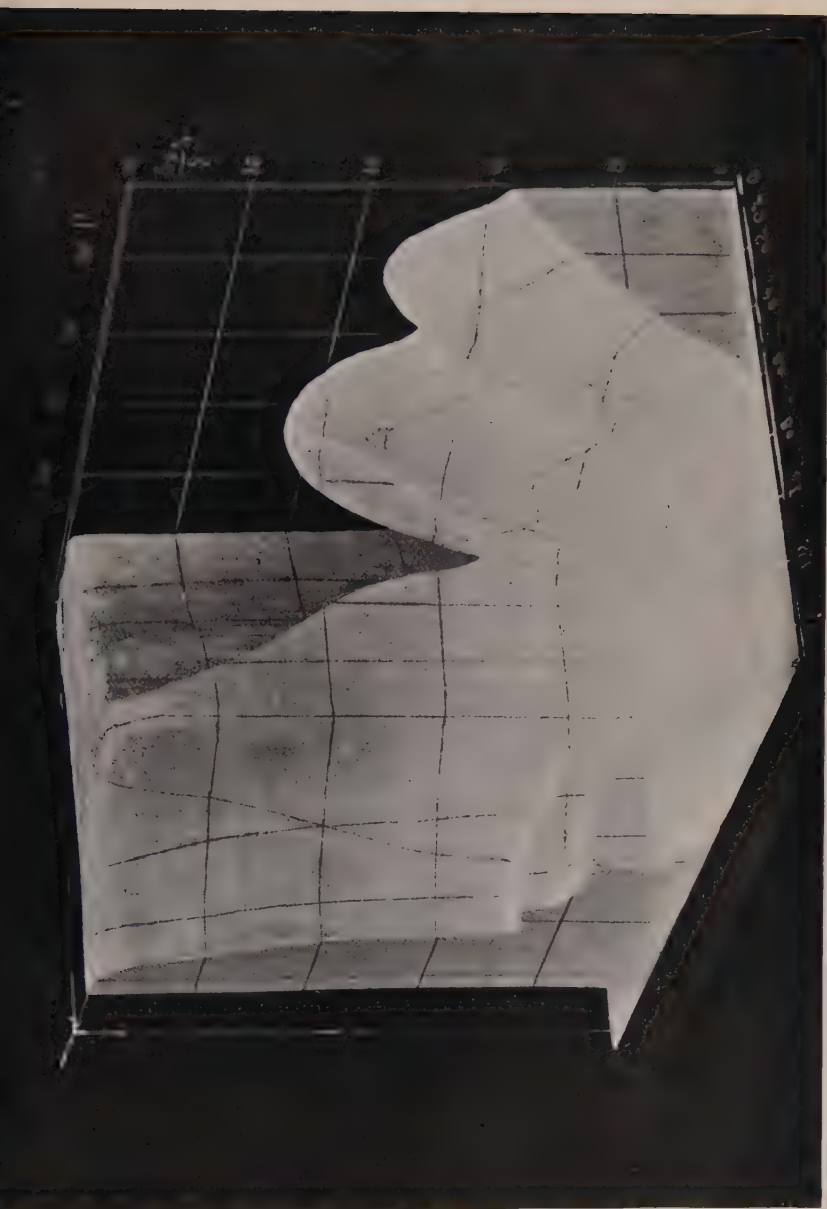
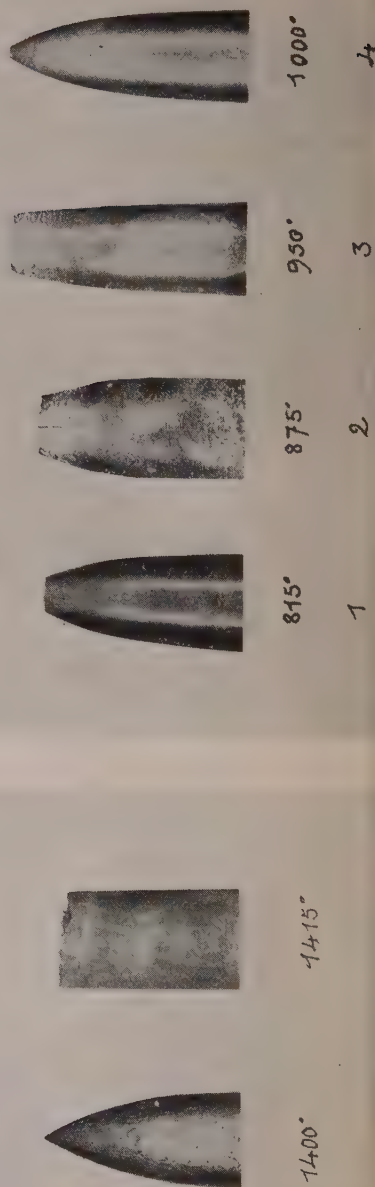


FIG. 31.—Metal as cast. Variation of the reduction of area in its relation to the temperature and to the percentage of carbon.

FIGS. 32 and 33. Appearance of Fractures.



FIG. 32. Steel 29 (C=0.15%) as cast.



DISCUSSION.

Colonel N. BELAIEW, C.B. (London), said he would like to take the opportunity of drawing attention to an interesting fact in the paper, namely, in regard to the very high temperatures used during certain tests. Some ten years ago he had the honour of being associated with Mr. Dupuy in some of his work when they were together in the laboratory of Professor Le Chatelier, and he made some very excellent experiments. The question studied by the author was one of paramount importance. For many years they had regarded such achievements as those of Mr. Dupuy as extremely difficult, and when careful students like the author had the co-operation of large works it was possible to achieve very important results. They had mechanical tests not only for temperatures under 1200° , but for those still higher. The results obtained were more or less what might have been expected, but it was very important to have them confirmed in such a convincing manner. They were under a great obligation for the assistance given by managers of works.

Mr. L. GUILLET (Paris) said that the paper presented by Mr. Dupuy was practically the first general investigation which had ever been carried out on the influence of high temperatures on iron and steel, and it was to be hoped that the experimental method suggested by Mr. Dupuy might be generally adopted. The subject had, it was true, been dealt with by Messrs. H. Le Chatelier, Charpy, and Dr. Rosenhain, but many points upon which Mr. Dupuy had shed considerable light had hitherto remained obscure. He (Professor Guillet) hoped that the investigations would be applied to the special steels. As was well known, there were a number of industrial problems of a chemical nature, the solution of which awaited the progress of investigations as to the manufacture of high tensile materials which would withstand very high temperatures, and problems such as those relating to, for example, the construction of gas-engines, would speedily be solved as soon as materials sufficiently strong were available. A sister Institute, the Institute of Metals, had already done useful work in investigating the tensile strength of aluminium bronzes at high temperatures, and he (Professor Guillet) had already endeavoured, in the *Revue de Métallurgie*, to summarise the results of some of those researches, and had drawn attention to the remarkable discovery made at the Imphy steelworks of highly complex iron nickel chromium tungsten steels (in which all four elements were found in the same alloy) which attained a high degree of tensile strength at 750° to 800° . He believed difficulties had been encountered in that respect in the punches used for the manufacture of shells.

To begin with tensile tests were carried out. Mr. Chevenard, having had some doubts as to the value of the results yielded by that mode of testing, carried out some viscosity tests as well, the principal of which was as follows: a wire made of the alloy was heated to a predetermined temperature, loaded with a weight, and maintained at constant temperature, and its behaviour observed. It was that test which led to the introduction of the improvements in manufacture to which he (Dr. Guillet) had referred. In the rolling tests, where it was necessary to have high tensile capacity, it was the use of those alloys which had allowed of such interesting results being obtained. There was, however, a point which had considerably pre-occupied Mr. Chevenard in regard to the viscosity test. When that test was carried out care was taken to raise the metal to a high temperature, and once that had been obtained the wire was broken. It was not sufficient in practice to heat a metal to 700° in order to ascertain how its tensile strength was modified; it was necessary to maintain the metal at that temperature for hours and sometimes even for days. The results differed according to whether the metal was tested as soon as it had attained that temperature or some hours after. They were greatly indebted to Mr. Dupuy for having placed that type of investigation upon an experimental basis, and it was to be hoped that the solution of the problem would be continued zealously until definite knowledge was acquired, not only as regards ordinary steels but likewise in regard to special steels after they had been heated for a lengthy period.

Dr. W. H. HATFIELD (Sheffield) said that the question of the strength of steel as affected by increasing temperature, particularly as pointed out by Mr. Guillet in connection with internal combustion engines, was a matter of very great importance. Their staff in connection with the research laboratory at the works had given very considerable attention to that problem, and they had examined practically the whole of the steels now being manufactured by their firms at ascending temperatures from 300° up to rolling and forging temperatures. Generally speaking, he had great pleasure in confirming the conclusions presented by the author. When they considered the matter quantitatively from the theoretical point of view, especially as the author dealt with that matter, a little more information was desirable. He hoped Mr. Dupuy would pardon him for criticising him in regard to the manner in which the data was put forward. The curves had been given, but the tables upon which those curves were constructed were not available. He thought it was extremely important that they should be printed, because there were several instances on record where authors had taken their curves from a small number of experiments. He thought they should have the actual evidence, so that they could, in comparing the curves, compare the actual readings. He would like to know how many determinations were made on a given steel.

Mr. DUPUY : Between forty and sixty for each curve.

Dr. HATFIELD, continuing, said that was excellent. Anything like forty or sixty determinations for the production of a curve were ample. He had, however, known of some papers where four or five determinations had been considered quite justifiable for numerous conclusions.

There was one point he thought they ought to give attention to. For example, there was a very important sentence on p. 98, in which the author said : "The regulation of the heating was always carried out in such a manner as to attain the required temperature at the rate of 20° per minute." That meant that 1200° was obtained in one hour. He would be disposed to criticise that as being rather fast heating. In their laboratories they took over two hours to reach 750° to 800° , and certainly much longer for 1200° . Again, the temperature was apparently only maintained in those experiments for five minutes. He (Dr. Hatfield) always made a point of maintaining the temperature for half an hour. That showed the difficulty of comparing the results of different series of experiments. At the same time he wished to say that he considered the paper very valuable.

He would like to refer to Mr. Schneider's paper, in which data was given in regard to the drawing operations. It was not stated whether the steel was high carbon steel or mild steel ; a consideration of that paper in the light of Mr. Dupuy's researches would materially enhance its value.

Sir HUGH BELL said that Mr. Dupuy preferred that further questions should be given in writing and care would be taken to give a proper reply. They must all be impressed with the importance of the paper to which they had listened, and they expressed their thanks to the author for his communication. It was obvious that in any question of great importance to the industry, it was essential to ascertain exactly the conditions to which they could submit their material and the various stresses at various temperatures which could be applied. Engineering chemistry was becoming a most important science, one indeed of the greatest importance, and the author had supplied very interesting and valuable information bearing on that science.

Mr. DUPUY, in reply, thanked Dr. Guillet, Colonel Belaiew, and Dr. Hatfield for their kindly references to his work. In regard to the information they had requested, the experimental curves were obtained by means of a very large number of points varying from forty to sixty for each steel, and not only from a consideration of the continuity. He had limited himself to joining up the ascertained points. They had likewise been more numerous taken in regard to that region of the diagram which revealed irregularities, in order to obtain greater accuracy. With regard to the rate of heating, he was aware in carrying out the experiments as he had done, that the heating was somewhat rapid. He had been faced to a certain extent with two alternatives,

either to spend much longer time in heating and to make very much fewer determinations, or somewhat to sacrifice accuracy in regard to the temperatures and so have a much larger number of points, so as to obtain results which would be, at any rate, comparable with each other and afford a preliminary and sufficient approximation. He did not, naturally, intend to compare them with the results obtained by other means, and, moreover, such results had not as yet been published.

Iron and Steel Institute.

THE "CHARACTERISTIC CURVES" OF THE
HEAT TREATMENT OF STEELS.

By ALBERT M. PORTEVIN AND PIERRE CHEVENARD.

At the outset of a quantitative investigation of the influence of cooling, it should be pointed out that recent researches on the hardening of steel have led to the establishment with, in this instance, great accuracy, of the mutual relationship which exists between the two fundamental factors of all heat treatment—the temperature of heating and the rate of cooling.

The final condition being a function of these two variables, it is easy to see the interest attaching to plotting a graphic representation of the result of a treatment by taking, for any given steel, these variables as co-ordinates. This method leads, as the authors will presently show, to the establishment of what they have termed the "characteristic curves" of the heat treatment of the steel in question. Such curves not only combine, within a single diagram, the fundamental data of every possible heat treatment, but they also afford, as will be shown, a means of defining accurately the annealed and hardened states of the particular steel, and therefore constitute the basis and indispensable preliminary of every treatment properly carried out with a particular object.

In order that such a graphic representation may be plotted properly, it is necessary that the values from which it is built up shall be susceptible of numerical definition so as to be capable of measurement. The authors will therefore first describe how they evaluate the rate of cooling and how they define the final state, that is to say, the result of the treatment.

Evaluation of the Rate of Cooling.—The authors will take into consideration only the case of simple heat treatments consisting essentially of heating to a temperature θ_c from which continuous cooling takes place according to a given law; a treatment which may be termed elementary, and which takes no note of more complex treatments in which the periods of heating may be

varied, or in which the external conditions during the course of cooling are modified.¹

The latter, as a matter of fact, cannot be represented by any simple graph and the problem becomes complex, although still remaining susceptible of being linked up with the fundamental data furnished by the characteristic curves.

It must be conceded, in any case, that the law of cooling always remains the same, and that it can be regarded, in the first approximation, as definable by the initial temperature of cooling θ_c and by a single other parameter. The latter has been so chosen as to indicate the rate of cooling, for which purpose there may be adopted :

1. The initial rate of cooling, that is to say, the rate at the temperature θ_c , or
2. The average rate between any two determined temperatures, or its reciprocal, the duration of cooling, taken between these two limits.

If these limits comprise the regions of the transformation of the steel in the course of cooling, the heat liberated during these transformations affects the values of the average rate of cooling, or its reciprocal, the duration of cooling. For this reason it appears more accurate to select the initial rate at temperature θ_c as the measure of the rate of cooling, as by this means it is possible to define the conditions under which cooling takes place, independently of the perturbations introduced by the intervention of transformations. This is the plan the authors will adopt in the case of coolings in air, or in gaseous media, for which Newton's law may be regarded as approximately correct. On the other hand, when cooling is effected by immersion in a liquid, the initial rate is found to be ill-defined experimentally, and it is preferable, in order accurately to determine the rate of cooling, to take the average rate between two temperatures far enough apart, or the time taken in traversing such a temperature interval.

Under these conditions a heat treatment would appear to be determined wholly by the values of two variables—the initial

¹ As, for example, quenchings at falling temperatures, quenchings in two stages, intermittent quenchings, or annealings carried out at oscillating temperatures.

temperature θ_c and the rate of cooling V . These are the two co-ordinates of the diagram.

DEFINITION OF THE RESULTS OF THE HEAT TREATMENT AND OF THE FINAL STATE OF THE STEEL.

In the case of a heat treatment having as its object the modification of the properties of a steel, the result can be defined by measuring those properties. It is obviously not possible to take all of them into consideration, as each would require its own special diagram. Amongst those properties the mechanical properties are, from an industrial point of view, the most important, but their measurement, when hard quenched steels are in question, is precarious and often illusory owing to experimental difficulties and errors.

The Brinell hardness Δ is still the property which appears, in this connection, the most important, the least uncertain, and the only one capable of being used on samples independently of their shape or dimensions. For these reasons the authors have adopted it to define the results of heat treatments. It should, moreover, be noted that for a given steel the heat treatment always modifies the mechanical properties, such as breaking stress R , elastic limit E , and hardness Δ , in the same direction, and the elongation A , the contraction Σ , the impact resistance ρ , and the angle of fracture on bending α , in the opposite direction.¹ A knowledge, therefore, of the variations undergone in respect of the hardness Δ yields information respecting those undergone by the other mechanical properties collectively.

The other physical properties are direct functions of the final state of the steel, that is to say, of the nature of its constituents. If, therefore, it becomes possible to define the latter, we possess a collection of data of the utmost value. For this purpose, however, the micrographic examination of the steel after treatment cannot alone be depended upon, for not only are the results first and foremost qualitative, and not susceptible of numerical evaluation, but they are also subject to considerable differences

¹ Apart from certain very special circumstances such as overheating, tempering in the vicinity of the transformation point, and the temper brittleness known as Krupp-Krankheit.

of interpretation, varying with the individual operator and the training and experience he possesses.

The state of the steel is, however, the immediate result of the transformations it has undergone during cooling, so that a quantitative evaluation of the intensity of these transformations during cooling affords a means of defining the final condition of the steel. The foregoing deserves some explanation, and the authors will therefore recapitulate briefly and simply the relations which exist between the transformations of a steel during cooling and the resulting constitution.

QUANTITATIVE EVALUATION OF THE INTENSITY OF THE TRANSFORMATIONS UNDERGONE DURING COOLING.

Two methods are currently employed to ascertain and estimate the transformations of a steel—the thermal method and the dilatometric method. With the latter alone the amplitude of the anomalies (variations in range which accompany the transformations) is independent of the rate of cooling. It is therefore this method which will be adopted by making use of the curves furnished by the differential dilatometer invented by one of the present authors.¹ The completeness and accuracy of the graph obtained with this apparatus allow of accurate measurements being taken along the curves.

It is known that if either the rate of cooling V , or the initial temperature θ_0 , be uniformly increased, the lowering of the transformation temperature on cooling is not continuous and that the accompanying phenomena take place in the following sequence :

The transformation which, to begin with, occurs solely at a high temperature Ar' occurs in two stages when the rate of cooling reaches a value V_0 , or when the temperature of heating reaches a value Θ_0 ; one at Ar' , at high temperature, and the other, Ar'' , at a low temperature (about 350°). Thereafter, Ar' gradually diminishes while Ar'' gradually extends, Ar' ending by disappearing, while Ar'' reaches a maximum intensity and then decreases and disappears in turn.

¹ P. Chevenard, *Revue de Métallurgie*, September–October 1917.

The presence of Ar' marks the formation of the complex α -iron + Fe_3C (pearlite or troostite), that is to say, of the annealed state; Ar'' marks that of the formation of the unstable solid solution α -iron — C (martensite), and therefore is characteristic of the hardened states. Absence of the transformation implies the persistence, at the ordinary temperature, of the solid solution γ -iron — C (austenite). These are the hyperhardened states.¹

When Ar' and Ar'' occur simultaneously, troostite (Ar') and martensite (Ar'') are obtained; these are the partially hardened states. The gradual disappearance of Ar'' involves the presence of an increasing amount of untransformed metal, that is to say, of austenite, and thus the partly hyperhardened state is obtained. The limit between the annealed state and the partially hardened state is the only one which can be accurately defined by the appearance of Ar'' . This is the transition through "the critical or minimum rate of hardening V_o " (when θ_c is constant), or through the "critical or minimum temperature of hardening Θ (when the rate of cooling V is kept constant²)."
 V_o and Θ_o are likewise the maximum rates and temperatures of annealing.³

The disappearance of Ar'' is, in certain steels, complicated by the intervention of a new reduplication of the low temperature transformation; there appears, below 200° , an Ar''' transformation which little by little supersedes Ar'' , and then disappears, in its turn.

In order quantitatively to evaluate the relative importance of these various ranges of transformation, the authors have conventionally adopted the following rules. Fig. 1 represents a typical differential dilatometric curve showing the three ranges Ar' , Ar''' , and Ar'' , simultaneously, the intensities being measured in the following way:

Ar'' , by the vertical distance of the consecutive inflexion point I_1 , from the extrapolated curve corresponding with the dilatationality at the stable hot-state.

Ar' , by the vertical distance of the consecutive inflexion point

¹ A. Portevin, Lectures before the École Centrale and the École Polytechnique, 1917-1919.

² A. Portevin, *Revue de Métallurgie*, 1917, vol. xiv. p. 707, and A. Portevin and Garvin, *Journal of the Iron and Steel Institute*, 1919, No. 1. pp. 559 et seq.

³ P. Chevenard, *Revue de Métallurgie*, 1919, vol. xvi. p. 75.

I_2 from the curve extrapolated from the inflexion point I_2 (a curve which may generally be identified with the tangent of inflection).

Ar''' , by its vertical amplitude measured at the surrounding temperature by extrapolating a curve below the inflexion point I_2 .

Figs. 2, 3, 4, and 5 give actual examples of these measurements taken on three experimental curves; when Ar' is missing, the amplitude of Ar'' is measured by extrapolating the curve of dilatability at the stable hot-state (Figs. 3 and 4), and the same is done in regard to Ar''' when both Ar' and Ar'' have ceased to exist (Fig. 6).

The variations in the intensity of Ar' supply a measure of the proportion of troostite, and those of $Ar'' + Ar'''$ indicate the quantity of martensite. There are thus indirectly ascertained the characteristics of the state of the steel, that is to say, of its constitution after cooling.

If curves of the variations in intensity of Ar' and $Ar'' + Ar'''$ be plotted in terms of one of the variables—for example, θ_c —it is possible by this method to determine :

- ⊙₀. The temperature of the appearance of martensite (appearance of Ar'') ;
- ⊙'₁. The temperature of the disappearance of the troostite (disappearance of Ar') ;
- ⊙'₁. The temperature corresponding with the maximum martensite ($Ar'' + Ar'''$ maximum), and
- ⊙₂. The temperature of the disappearance of the martensite ($Ar'' + Ar'''$ nil) ;

and therefore to ascertain the zones corresponding with the annealed, hardened, and hyperhardened states. Similarly, on taking the rate of cooling, the rates $V_0, V_1, V'_1, V_2, \dots$ limiting these various regions, can be found.

The most important and the best ascertained of these limits is that which separates the annealed states from the hardened states, and which is distinguished by the appearance of Ar' and by a rapid increase in the hardness, in terms of the variable under consideration. The next in importance is the maximum of Ar'' or of $Ar'' + Ar'''$, which is likewise the maximum of the hardness. Its practical importance is obvious, and it also marks the limit of the hyperhardened states.

The limits of the disappearance of the troostite and the martensite are much less important and less accurately determined,

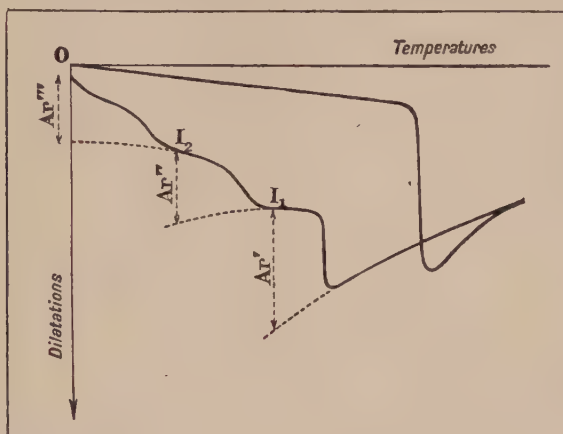


FIG. 1.

nor should too much reliance be placed on their indications,

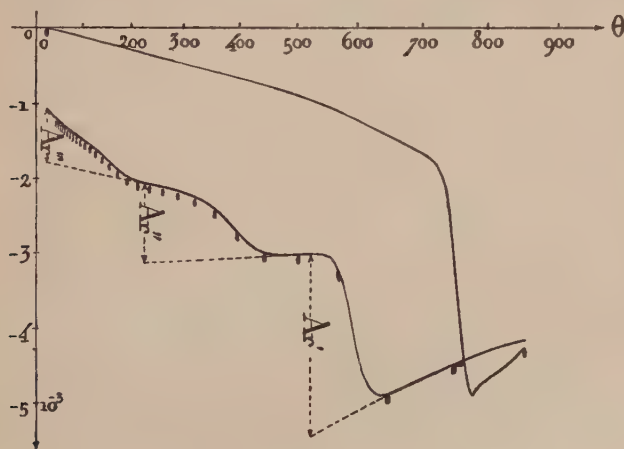


FIG. 2.

or on the fact that experimentally the disappearance of the troostite and the maximum of martensite are not found to be in

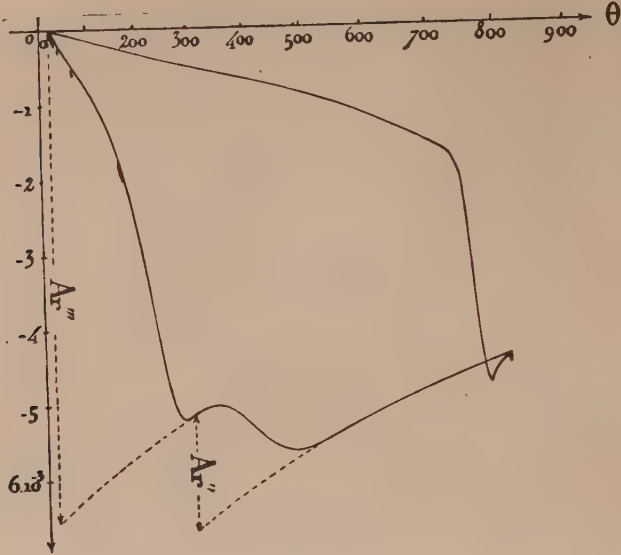


FIG. 3.

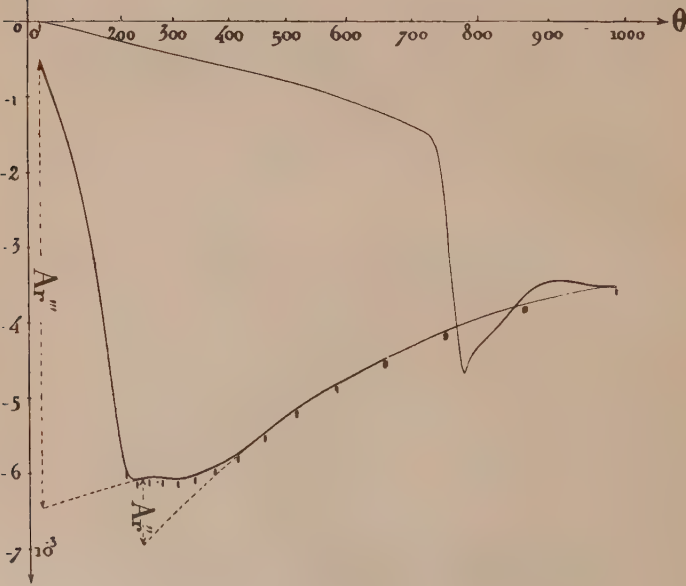


FIG. 4.

agreement. There is nothing, moreover, to prevent these secondary zones overlapping one another, which sometimes leads to the existence of the mixture troostite-martensite-austenite. What is really of importance in these hardened states is the hardness. An investigation of the latter will therefore take the place

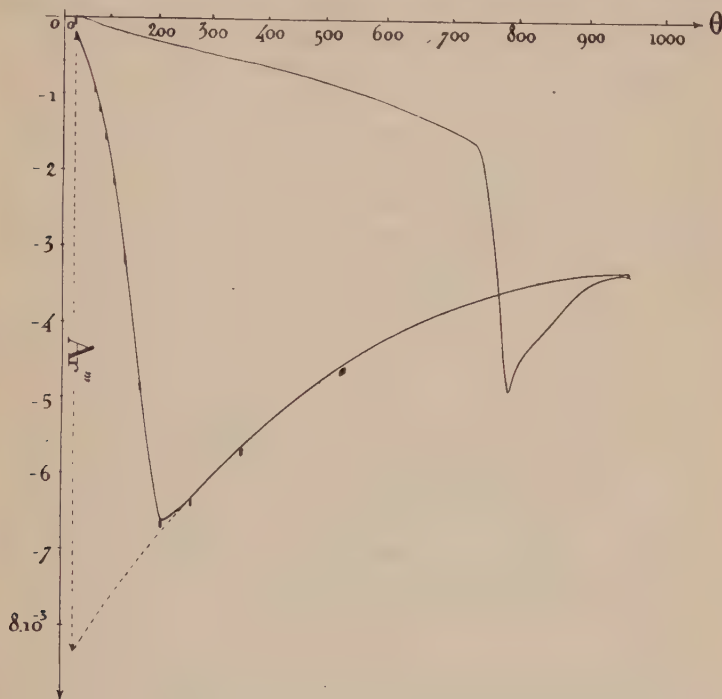


FIG. 5.

of questions relating to the constituents, the more so as, by ascertaining the position of the maximum hardness and examining the drop in the hardness in hyperhardened zones, it will be equally possible to ascertain the limits of the commencement of hyperhardening and of the disappearance of martensite.

CHARACTERISTIC CURVES.

By varying simultaneously the initial temperature of heating θ_c and the rate of cooling V_c , it is possible to plot the geometrical

area of the various characteristic limits of the different states in terms of θ_c and of V , taken as co-ordinates in the plane $\theta_c V$. By these means are obtained the "characteristic curves of heat treatment for the given steel." They comprise, more particularly:

1. The curve $\theta_c V_0$ or Θ_0, V , giving for each temperature θ_c

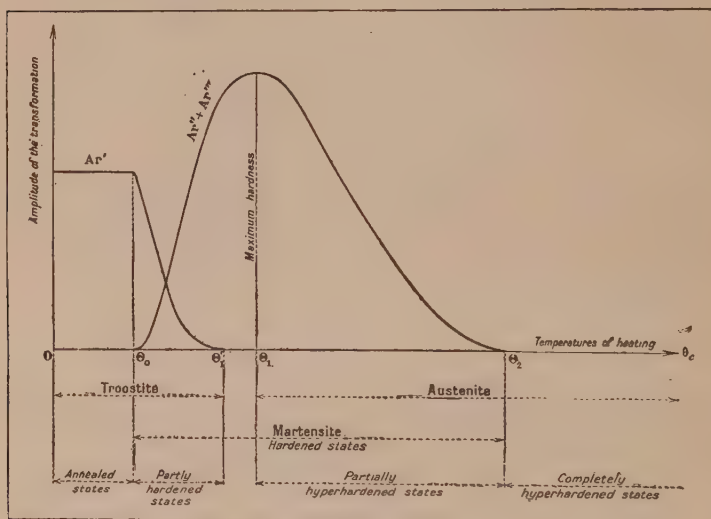


FIG. 6.

the critical rate of hardness V_0 , or else the maximum temperature of annealing Θ_0 for each rate V of cooling.

This curve separates the annealed states, devoid of martensite, from the hardened states, containing martensite. It is therefore the curve of the annealing limit. It rigorously defines the hardening capacity of the steel.

2. The curve $\theta_c V_1$ or Θ_1, V , of maximum hardness, or of the maximum amount of martensite. This is the curve of maximum hardening, which similarly marks the limits between the partially hardened and the partially hyperhardened states. This diagram is completed by adding, in the region of the hardened states, curves of isohardness which serve to mark the limits of the various hardened and hyperhardened states. These are the level curves

of the surface $(\theta_c V, \Delta)$ which is formed from two planes, the intersection of which is continued in the direction of the curve limiting the annealed state and shows a crest extending towards the curve of maximum hardening. By these means are obtained a complete graphic expression combining all the conditions essential to hardening. It will be seen that the latter problem is entirely indeterminate, as any particular point on the co-ordinates θ_c and V may occur within the area of the plane. Even if it be sought definitely to determine amongst the hardened states a particular state corresponding with the hardness to be attained, its selection would be defined by the co-ordinates in any one of the points in the corresponding isohardness curve. Amongst this infinity of solutions choice can be made of the most suitable by bringing into consideration the practical conditions obtaining, such as rate of cooling and temperature of heating, as well as the parasitic phenomena such as superheating, deformation, internal stress, cracks, &c., accompanying the heat treatment.¹

EXAMPLES OF CHARACTERISTIC CURVES.

The plotting of a diagram of characteristic curves for heat treatments comprises a considerable number of experimental determinations forming a complete heat-treatment research on steel, of which investigations hitherto published afford no parallel. As has already been said, the most important of these curves, the curve showing the limit of annealing or curve of the commencement of hardening, is one which can be plotted with considerable accuracy, as it can be exactly determined by three methods simultaneously—micrography, the transformation-point determination, and by ascertaining the hardness.

It is possible to quote certain examples of these latter curves in, however, a somewhat fragmentary state. In the research by Edwards, Greenwood, and Kikkawa,² on chromium steel containing 0.63 per cent. of carbon and 6.15 per cent. of chromium, there will be found (Fig. 15 of the original memoir) data allowing of the plotting of this curve (as well as of portions of the isohardness curves) within the range comprised between periods of two to

¹ See A. Portevin, *Chimie et Industrie*, 1919, vol. ii. p. 1154.

² *Journal of the Iron and Steel Institute*, 1916, No. I. p. 114.

twenty minutes cooling between 836° and 546° . These authors also give, within the same range, the curve of the disappearance of Ar' (Fig. 14¹). One of the present authors² has shown, partly by the dilatometric method, curves of the annealing limit of carbon steels containing 0.22, 0.30, 0.39, 0.49, 0.59, and 0.82 per cent. of carbon. Finally, Fig. 7 shows³ the annealing limit and maximum hardness curves of a high-speed chromium-tungsten steel (carbon, 0.4 per cent.; chromium, 4.5 per cent.; tungsten, 18 per cent.). This diagram presents the three ranges of the annealed, partially hardened, and hyperhardened states.

The authors have plotted characteristic curves for various types of steel selected amongst those most important industrially and most interesting from the variety of states practically obtainable, notably manganese steels readily susceptible of being hyperhardened, and nickel-chromium steels. They propose to give the results obtained, up to the present, on one of the latter steels.

CHARACTERISTIC CURVES OF A NICKEL-CHROMIUM STEEL.

The nickel-chromium steel had the following chemical composition:

	Per Cent.
Carbon	0.50
Manganese	0.30
Nickel	2.65
Chromium	1.60

The researches were made by the dilatometric method on samples 3.5 millimetres in diameter and 50 millimetres in length, and supplemented by determinations on the Brinell hardness carried out under the following experimental conditions.

Conditions of Heating and Cooling.—Heating was effected in an electric resistance furnace with a very nearly constant rate of 250 degree-hours for all the tests. The temperature of heating θ_c is shown in the diagram registered by the dilatometer.

Four methods of cooling were employed:

1. Spontaneous cooling in air after withdrawal from the furnace.

¹ Original memoir.

² P. Chevenard, *Revue de Métallurgie*, 1919, vol. xvi. p. 77.

³ *Ibid.*, 1920, vol. xvii. p. 688.

2. Cooling in a little metal muffle formed of a tube of baros (an alloy devoid of transformations), heated together with the sample and air cooled after withdrawal from the furnace.

3. Cooling within the oven by interrupting the heating current.

4. Retarded cooling in the furnace by gradual reduction of the heating current.

In each instance the temperature on cooling decreased closely in approximation with Newton's law. On the other hand, the rate of cooling at any given temperature is practically independent of the temperature of heating, so that a typical cooling curve corresponds with each mode of cooling. Hence the employment of the "initial rate" to characterise the rate of cooling, and, as Newton's law is very closely followed, the points relating to any given mode of cooling distribute themselves in the final diagram ($\theta_c V$) along a line cutting the axe of the abscissæ at the surrounding temperature.

Measurement of the Dimensions characterising the State of the Steel.—Figs. 2, 3, 4, and 5 give examples of curves registered, with dimensions of the amplitudes of the transformations, as already described. These dimensions allow of curves being plotted for each mode of cooling, giving the variations in the amplitude of Ar' , of Ar'' , of Ar''' , and of $Ar'' + Ar'''$ in terms of the temperature of heating. Figs. 8, 9, and 10 give these curves for the three methods of cooling (1), (2), and (3), as well as curves of the Brinell hardness Δ in terms of the same variable θ_c . This hardness was determined by a series of ball impressions (1.6 millimetres diameter and pressure of 25 kilogrammes) distributed along the length of the test-rod, the cylindrical surface of which, with this object in view, had been lightly planed under water (to obviate any tempering effect due to heating), so as to obtain the little flat surface necessary for this kind of test. Each test-bar thus received seven ball impressions, the diameters of which were measured under the microscope. The tests were not considered satisfactory, except when the individual divergences were less by 5 per cent. from the mean.

Results Obtained.—An examination of Figs. 6, 7, and 8 brings out clearly the sequence of phenomena of hardening already described. The particular interest attaching to this steel is that it affords an excellent example of the double stage occurrence

of Ar'' and Ar''' of the low temperature transformation, a doubling hitherto but little investigated. Here the appearance of the two points Ar'' and Ar''' takes place simultaneously at the temperature Θ_o , and at the same time as the intensity of Ar' begins to decrease. There is thus, in this instance, a triplication of the transformation. Ar'' , which is nil at Θ_o , increases until it attains a

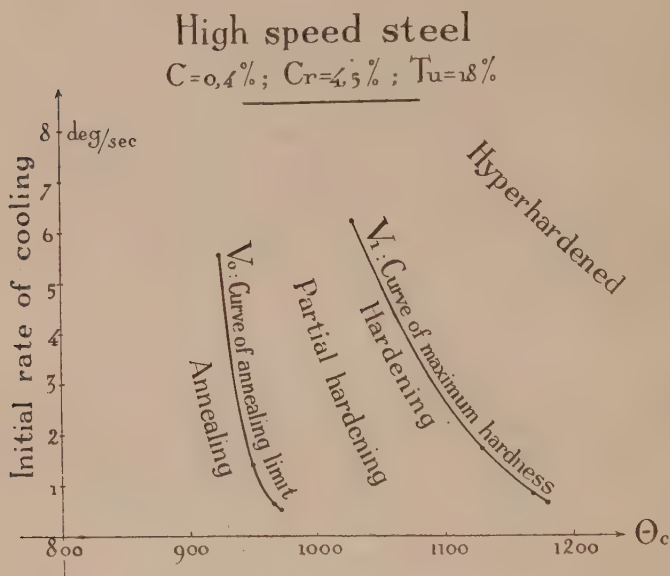


FIG. 7.

maximum of intensity, and then decreases almost to zero while the amplitude of Ar''' increases steadily the while. The total intensity, $Ar'' + Ar'''$, which determines the quantity of martensite formed, varies in the inverse ratio of that of Ar' (troostite).

The rise of the temperature, θc , reached tends to make the reduplication of Ar'' , Ar''' , at low temperature disappear. As this rise of temperature leads to the completion of the solutions of the iron carbide and to the homogeneity of the solid γ solutions this fact conduces to support the view taken by the authors¹ as to the connection between the existence of multiple points at

¹ *Comptes Rendus*, 1921, vol. clxxii. p. 1490.

low temperature and the lack of uniformity of concentration of the solid solution.

The rate of cooling acts in an analogous way, the increase in the rate of cooling tending to make Ar'' disappear. The two points Ar'' and Ar''' exist nevertheless in the case of method 4

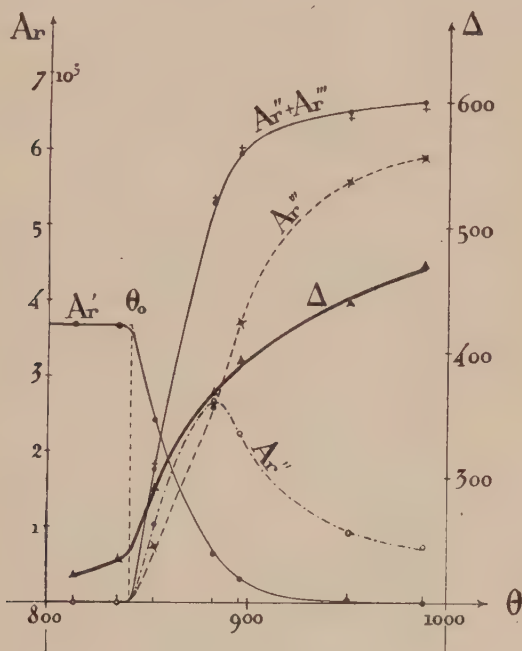


FIG. 8.

of cooling, so long as the temperature of heating does not exceed 850° to 875° . With the steel in question the authors were unable, within the limits of heating and cooling adopted, to obtain hyperhardening. The Δ curves and those of $Ar' + Ar''$ show that the maximum is not attained, or, at any rate, is not appreciably exceeded.

When the amplitude $Ar' + Ar''$ becomes practically constant it will be seen that at the same time the rise in hardness becomes much less rapid, which shows that the neighbourhood of maximum hardness is being approached. In order readily to attain

to hyperhardening it would be necessary to have recourse to much higher rates of cooling, which the authors have not had time to undertake.

The diagram of the characteristic curves summarising the

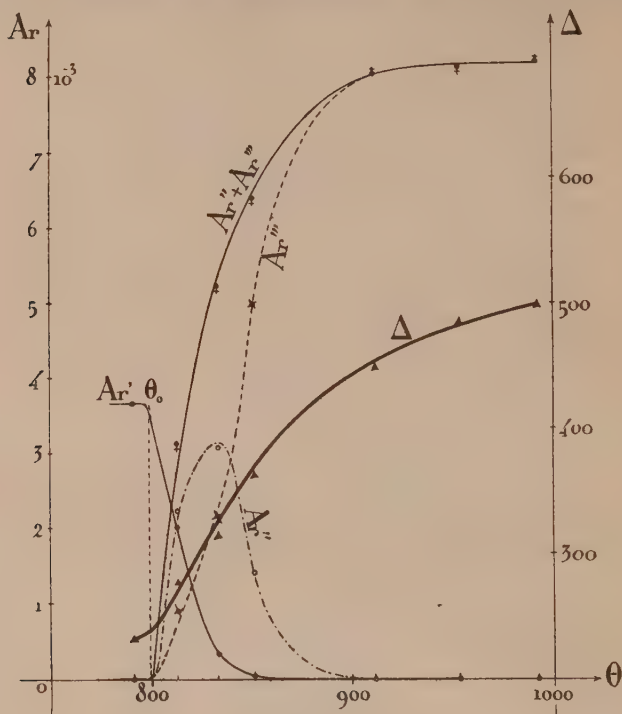


FIG. 9.

whole of the determinations is given in Fig. 11. It comprises the curve of the limit of annealing, or curve of the critical rates of hardening V_0 , separating the region of the annealed states from that of the hardened states; and in the latter region the succession of curves of isohardness corresponding with the values of Brinell hardnesses varying from 50 to 500.

As has been said, the isohardness curves relating to hyperhardening were not taken, so that this diagram does not exhibit the curve of maximum hardness. Moreover, it cannot be hoped to collate into one plan and on one common scale the entire

appearance of characteristic curves, given the considerable range of cooling rates obtainable.¹ It is necessary to limit the inquiry, in the first instance, to the most useful and most serviceable portion, for each steel. Even within these limitations the diagram

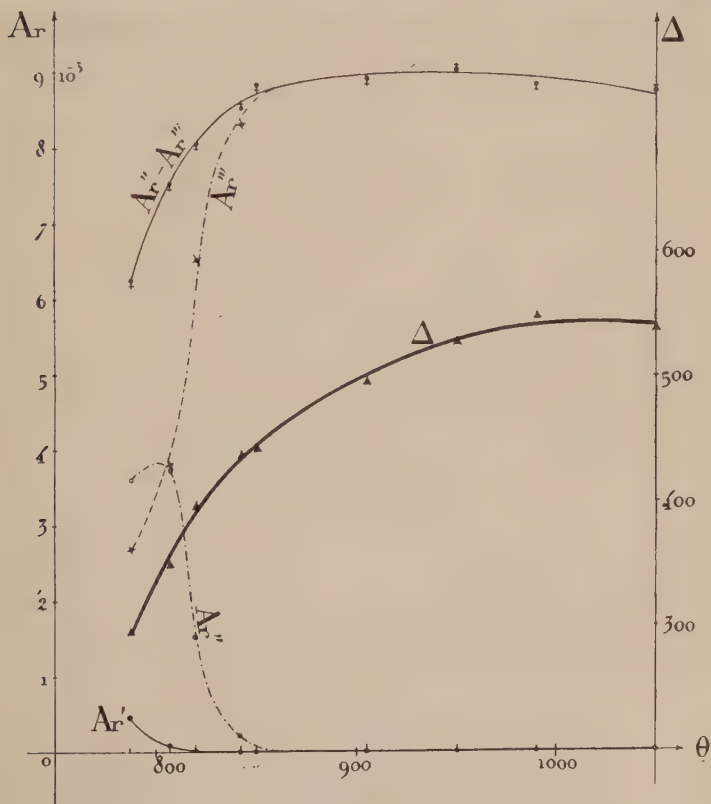


FIG. 10.

of characteristic curves furnishes a collection of facts as to heat treatments incomparably superior to the often somewhat inchoate collection of numerical data hitherto accumulated in connection with the heat treatment of steels. Very often the basal con-

¹ If it were desired to reproduce on the diagram, Fig. 11, and on the same scale of rates, the portions of the critical curves of the hardening of carbon steels actually plotted, the space required for their development would amount to 40 yards in height.

siderations relating to mass and rate of cooling cannot be deduced from these observations, or expressed numerically, so that it becomes impossible to foresee what modifications may be required when the size of the pieces or the nature of the cooling medium is changed.

Numerous and important researches have now supplied data

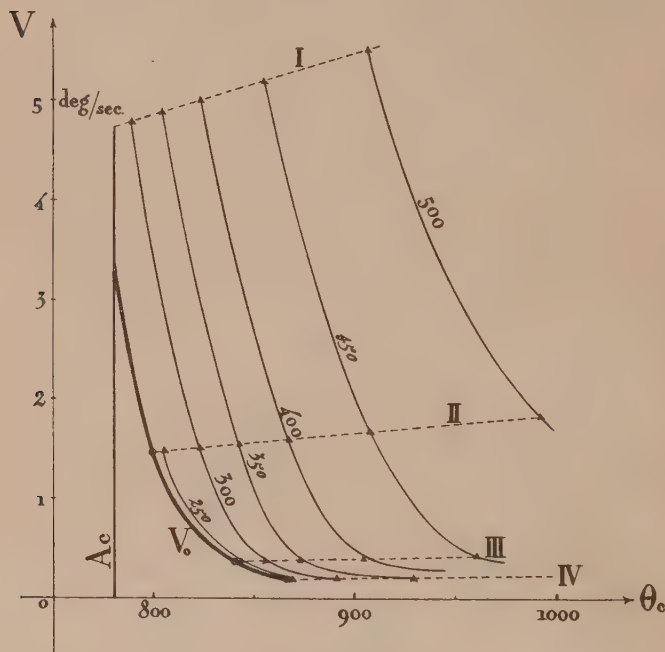


FIG. 11.

as to the cooling capacity of liquids and gases, and in order to apply them to practice there should now be plotted, with no less accuracy, and for each type of steel, the curve showing the relationship between the rate of cooling and the effect of treatment, taking into consideration, more particularly, the part played by the second of the fundamental variables—the temperature of heating.

It is to the questions raised by the latter problem that the plotting of the characteristic curves can supply answers, as they combine, in a readily utilisable form, all the data furnished as

to heat treatment and are the only means of ascertaining, with any degree of precision, the hardening capacity of a given steel.

INFLUENCE OF OTHER FACTORS ON HARDENING.

In the foregoing the authors have taken into consideration only the influence of the two fundamental variables, temperature of heating and rate of cooling, on the results of heat treating a steel of given chemical composition. But, given these factors, the effect of treatment depends on other secondary factors; the law, and period of heating, and the original structure of the steel, the final state being a resultant of all its previous heat-treatment history.

The characteristic curves are not therefore strictly applicable except when the latter factors are constant, which might lead to the belief that their signification and utility must be correspondingly restricted. Without, however, entering into details, it will suffice to observe that the original state, the result of the previous heat-treatment history, can be reduced to a typical form by preliminary heat treatments, and that, besides this, the perturbations which may be introduced may in many instances be entirely obviated by an appropriate selection of the law and duration of heating. In other words, in this group of secondary variables it is possible to so arrange matters that some of them will destroy the effect of others, and that the thermal behaviour of the steel shall agree with the data given by the diagram of characteristic curves of heat treatment.¹

¹ An exception must be made to the foregoing: that presented by certain nickel-chromium steels which are abnormally irreversible (A. Portevin, *Revue de Métallurgie*, 1913, vol. x. pp. 797 and 808).

DISCUSSION.

Mr. L. GUILLET (Paris) said that the paper by Messrs. Portevin and Chevenard directed attention to the huge amount of work which had been done within recent years on the investigation of hardening phenomena. He (Dr. Guillet) would like to remind them that the prototype of all special steels, the manganese steel discovered by Sir R. Hadfield, was a hyper-hardened steel. At the Physical Congress held in 1900, a period at which he (Dr. Guillet) had hardly commenced to study such questions, the great British scientist, Sir W. C. Roberts-Austen, a friend of the great French scientist, Osmond, stated that there was no operation which was so much the sport of faulty practice as that of hardening. He drew attention to the liquids employed in that operation, and quoted an ancient practice which consisted in taking the blood of a youth of fifteen years of age, at the new moon in the month of May, and of adding certain salts to that blood so as to obtain a liquid which had high hardening powers. Fortunately some progress had been made since those times. The investigations of Osmond and of Le Chatelier had shown the value to be assigned to the different factors. What Mr. Chevenard had not told them was the apparatus used in the laboratory for carrying out those investigations, where the appliances ordinarily used, appliances which could be put into the hands of young beginners, and the dilatometer, which was known all over the world by the name of Mr. Chevenard, had afforded a means of studying those curves much more closely. He (Dr. Guillet) wished to instance an exceedingly interesting example of its employment: it had for a long time past been known that the gold-copper alloys required hardening before they could be rolled, and that that was always done before such an operation. Quite recently the apparatus devised at the Imphy steelworks by Mr. Chevenard had enabled two of his (Dr. Guillet's) friends, Messrs. Portevin and Jean Durand, to determine the transformation points of those alloys, and they had been able to demonstrate that hardening resulted in the formation of a solution of a gold-copper compound which facilitated rolling. Whether it was a question of steels, of ordinary bronzes, of tin bronzes, or even of duralumin, the phenomena of hardening could all have light thrown upon them by the investigation of the transformation points at high temperatures.

It was possible to establish that theory of hardening by other investigations. A final consideration to which attention should be drawn was the importance of the period of heating in regard to certain steels and more particularly high-speed tool steels, of which a commercial example could be given. When it was desired suitably to harden a metal, it was necessary to bring it to a very high temperature.

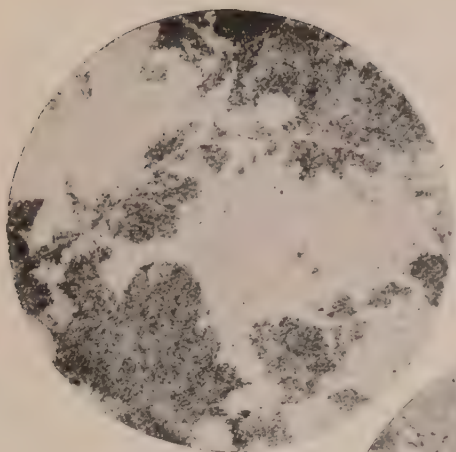


FIG. 1. $\times 500$.

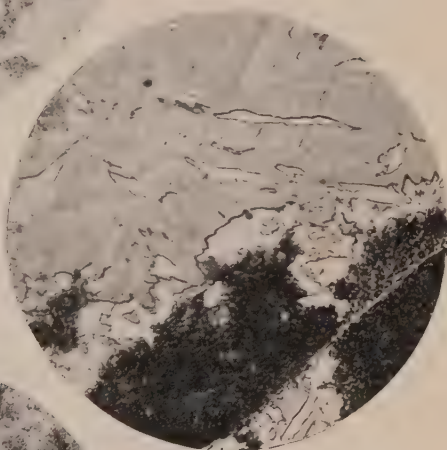


FIG. 2. $\times 1200$.

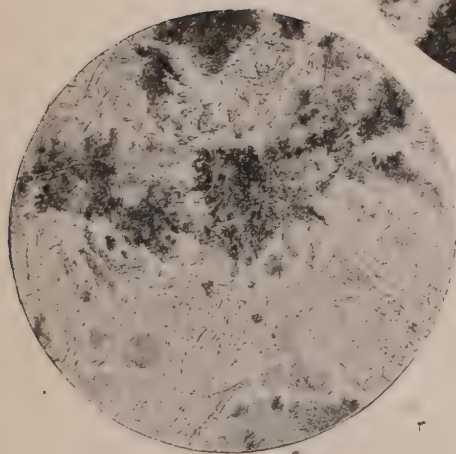


FIG. 3 $\times 500$.

That introduced no difficulty when it was a question of tools the shape of which was simple ; but, on the other hand, in the case of milling cutters, it was necessary to quench them at a temperature in the vicinity of melting point. Long ago, in a memoir published in the *Revue de Métallurgie*, he (Dr. Guillet) had drawn attention to the influence of the duration of heating prior to quenching. Thus, by a prolonged heating at 1000° , more particularly in the case of chrome steel milling cutters containing from 5 to 6 per cent. of chromium and 18 per cent. of tungsten, it had been found possible to obtain results nearly as satisfactory in regard to their working as when hardening was carried out at 1250° . Apart from the inconvenience of the slower process, such a method implied the absolute necessity of taking precautions, for when the heating had to be carried out in a saline bath, it was exceedingly seldom that the salt did not end by corroding the metal. The atmospheric or gas muffle was a detestable appliance. It was best to carry out the heating in a gas-fire furnace with a reducing flame. It often sufficed, however, to adopt the simpler plan of heating the pieces in iron turnings, when no disadvantages ensued. At two works such a process was employed and the cutters were heated at 1000° . Uniform results were obtained without the teeth of the cutters being deteriorated. Such investigations had immediate results. Hardening was now carried out in liquids, the influence of which was known at known rates and at known temperatures with known steels, and 95 to 96 per cent. of the results were successful. Twenty-five to thirty years ago, as was well known, the hardening of lathe tools was always a messy job.

SIR ROBERT HADFIELD, Bart., F.R.S., Past-President, said they were much indebted to the authors for their excellent papers. The Institute had always been under an obligation to Frenchmen for the work done in investigating special steel. It must be a great satisfaction to all to see among them at the meeting Mr. Pourcel, who in the distant past and right down to the present time, had been one of the leading pioneers in that great work. They could never forget the work done by Messrs. Pourcel, Euverte, and Gautier, and the metallurgical world would always remain under an obligation to them.

He had taken the opportunity afforded by the visit to Paris to make an inspection of the apparatus provided at the École Polytechnique, where he had certainly seen the scientific handling of steel to a degree of perfection in the wonderful apparatus which he had seen there. He offered his hearty congratulations to the two investigators, Messrs. Portevin and Garvin, who had that particular research work in charge. He would strongly recommend those remaining in Paris, if they could find time, to pay a visit to that institution, and see the apparatus at work. He was astonished at the accuracy with which the heat treatment and quenching operations were controlled and the curves taken.

Sir HUGH BELL said the meeting would be glad to accord their thanks to the authors of the paper. It was impossible to exaggerate the importance of the information conveyed. In the early days of steel production the manufacture of fine steel was a matter purely of empiricism, and that work was done with an extraordinary amount of success which present day workers had only been able to equal after the most careful investigations. In those researches Sir Robert Hadfield himself had taken no small part. It was really wonderful how the old smiths and steelmakers got their reputation for producing sword blades which were so famous. It was very evident that the ancient worker knew exactly what he was doing but did not know why he was doing it. The extraordinary quality reached was very remarkable indeed. English people, and no doubt their friends in France, would recollect the blade which had come down to posterity under the name of Excalibur, which was no doubt forged by some extremely skilled producer of steel.

*CORRESPONDENCE.*¹

Mr. J. H. WHITELEY (Saltburn) wrote that Messrs. Portevin and Bernard appeared to have included under the term "coalescence" two distinct processes. True coalescence might be preceded by a breaking up of the pearlite laminæ into minute particles; those then tended to come together and merge into the larger ones. The first was a process of separation or divorce, and only to the second could the term coalescence be strictly applied.

Howe and Levy were the first to show that both divorce and coalescence were seemingly capricious in their action. Some areas divorced very quickly; others very slowly. He had repeatedly confirmed that. It was surprising to find how much divorce could take place in a piece of hypoeutectoid steel when cooled down through the critical range at a rate of even 20° a minute. Areas of pearlite could be found in which the laminæ had entirely broken up and others partly. The only explanation advanced by the authors of the phenomena of divorce and coalescence was that of the mutual solubility of cementite and ferrite. Of that there did not yet appear to be any really definite proof, but, if it were really the means by which coalescence occurred, a considerable length of time must be required to allow the slow processes of solution and diffusion to continue until divorce or coalescence was completed. The solubility of cementite in ferrite was admittedly very small and consequently time must be an essential factor. He (Mr. Whiteley) was of opinion, therefore, that the fact of the capriciousness

¹ The two papers next following were taken as read with the previous one and discussed together.

of those effects as indicated above was entirely against that explanation. It seemed much more feasible to conclude that divorce, at any rate, was due to the surface tension which existed at the interfaces of the lamellæ of cementite and ferrite which, as soon as conditions permit, caused the lamellæ to break up into small particles. The fact that the coalesced particles were invariably rounded and without crystal outline also indicated that surface tension forces were at work. There appeared to be no reason why the cementite particles should not have a crystal outline if coalescence were entirely due to intersolubility of the two constituents. The evidence available would therefore go to show that at temperatures above about 650°C . minute particles of cementite were able to coalesce not only by solution and deposition but also by moving bodily towards each with some degree of velocity.

Mr. A. HULTGREN (Gothenburg, Sweden) proposed to discuss the structure of the tungsten steel (carbon, 0.4 per cent. ; tungsten, 5.4 per cent.) illustrated by Mr. Portevin in Figs. 1 to 3 and assumed to represent true equilibrium. Leaving the free carbide particles aside for a moment, three structural fields were plainly visible in Fig. 1. It would have been of great interest had the author determined by experiments in what order those separate fields formed during cooling. It seemed plausible that the white areas were ferrite first separated out of the austenite. The author assumed the needles in Fig. 2 to be Fe_2W . If that were so, the areas of acicular structure would most naturally represent a binary eutectoid ferrite, Fe_2W , and the dark troostite areas a ternary eutectoid containing ferrite, Fe_2W , and probably a carbide, those areas being the last to form. That explanation would satisfy the conditions of true equilibrium. However, the arrangement of the three structural fields did not readily suggest that interpretation, but, in his (Mr. Hultgren's) opinion, rather that the order of formation possibly were : ferrite, troostite, acicular areas.

In support of that suggestion he wished to call attention to an analogous case represented by Plate XI., taken from an investigation on tungsten steels made by him.¹ Specimens of a tungsten steel (carbon, 0.94 per cent. ; tungsten, 2.9 per cent.) were allowed to cool from 1200° in a furnace, consequently fairly slowly but not as slowly as in the author's experiment. The specimen shown in Fig. 1² was withdrawn from the furnace when reaching 584° and quenched, that of Fig. 2 at 540° , and that of Fig. 3 at 500° , both those also being quenched immediately. By that method the different stages of structural development were fixed. Disregarding the hyper-eutectoid cementite first separated out as a consequence of the high carbon content, troostite was the first constituent formed (Fig. 1), then

¹ "A Metallographic Study on Tungsten Steels." Wiley, New York ; Chapman & Hall, London, 1920.

² All specimens were etched in 1 per cent. solution of nitric acid in alcohol.

ferrite needles and seams, which he termed "secondary ferrite," separated from the remaining austenite (Fig. 2), finally leaving partly needle-shaped areas, which at least decomposed. Fig. 3 did not, however, represent true equilibrium, as was proved by the fact that in arresting the cooling at 600° and maintaining that temperature for three hours, the austenite passed entirely into troostite, no opportunity being left for the secondary ferrite to form. The peculiar secondary ferrite separation, to which he (Mr. Hultgren) attributed the so-called "lower critical point" in cooling curves of tungsten steels, was prominent in nearly all his tungsten steels (carbon from 0.47 to 1.29 per cent.) when cooled from high temperature.

In view of the great similarity between the author's Fig. 1 and his (Mr. Hultgren's) Fig. 3 (both showed troostite areas and acicular fields), additional experiments seemed desirable before the authors' interpretation could be accepted. Considering the known stabilising effect of heating tungsten steel to as high a temperature as 1300° , it did not seem impossible that true equilibrium was not attained, notwithstanding the very slow rate of cooling. He hoped the authors, in the data submitted above, would find reasons to make new experiments with their tungsten steel in order to determine the successive order of formation of the constituents found, for instance by quenching from different temperatures during cooling.

As to the carbide observed by the authors and assumed to be tungsten-carbon, he wished to ask whether it was coloured by sodium picrate. Tungsten-carbon, a typical constituent of tungsten steels of high carbon content, was not coloured by that reagent, as he (Mr. Hultgren) had shown elsewhere.¹

¹ *Loc. cit.*

Iron and Steel Institute.

ON CONSTITUENTS FOUND IN TUNGSTEN AND MOLYBDENUM STEELS.¹

BY ALBERT M. PORTEVIN (PARIS).

THE practice of annealing, followed by exceptionally slow cooling, is one of extreme interest from the point of view of researches on the structure of special steels. Such treatments not only afford a means of securing a general enlargement of the structural features, so as to allow of a closer scrutiny of their details and peculiarities, but also lead to true states of equilibrium being obtained.

By adopting this mode of systematically investigating the special steels the author has been able to effect not only the disappearance of obviously hard states (martensitic or austenitic) hitherto observed exclusively in certain chromium and manganese steels,² but has been also able to establish the fact that certain structures which might have been regarded as being in equilibrium, are superseded by others which, by the separation of constituents not hitherto described, represent, in the sequel, an even more advanced state of equilibrium.

Examples, in the case of certain tungsten and molybdenum steels, will be described. The author would wish to point out, however, in this connection that nickel steels, or, at any rate, those which he has studied by this method, containing up to 30 per cent. of nickel and 0 to 0.8 per cent. of carbon, undergo profound modifications in structure, but that the new structures thus created are complex, and that their interpretation presents very great difficulties, owing to the uncertainty surrounding our knowledge of the stable iron-nickel system. Indeed, even the knowledge and insight of F. Osmond, to whom in 1912 the author submitted these structures, failed to find an explanation of them. For this reason the author has himself forborne to describe them and has limited himself hitherto to

¹ For discussion see pp. 139-140.

² A. Portevin, *Comptes Rendus*, 1911, vol. cliii. p. 64; 1917, vol. clxv. p. 62. *Assoc. Inter. des Essais Matériaux*, November 1911.

a description of the variations in electric resistance which accompany them.¹

I. TUNGSTEN STEELS.

An investigation of the structural variations resulting from annealing tungsten steels and then cooling them extremely slowly, has led the author to the following conclusions, amongst others, in regard to alloys containing from 0·1 to 0·4 per cent. of tungsten :

The structure of these "normal" steels is described as consisting of ferrite associated with pearlite (Guillet, Swinden), or even as being devoid of pearlite (K. Honda and T. Murakami).

After annealing at about 1300°, followed by a cooling extending over 75 hours, down to 200°, the structure is completely altered. Fig. 1 (Plate XII.) shows a steel containing 0·4 per cent. of carbon and 5·4 per cent. of tungsten which has undergone this treatment. There will be observed a network formed of light and dark areas separating regions occupied by a constituent differing from any hitherto known. This is apparently a complex, consisting of needles, and is met with alike in steels with a lower carbon percentage (0·1) and in steels with a higher tungsten percentage (7·55). Examined under high magnification there can plainly be seen needles arranged (Fig. 2) similarly to those of the martensite of hardened steels. These needles can be coloured by a solution of sodium picrate in soda (Fig. 3). This characteristic, added to their abundance in steels with so low a carbon content (which prevents them being taken to be carbides) shows them to be a tungstide, Fe_2W . The arrangement of the structure (Widmanstaetten) shows them to have separated gradually from a crystallised medium, which is the solid solution $\text{Fe}-\text{Fe}_2\text{W}$. Now, in the iron-tungsten diagram the regional limit of this solid solution, that is to say the solubility line of Fe_2W in the solid state, is a curve showing a decreasing solubility as the temperature rises, and ending at 9 per cent. of tungsten at ordinary temperature (K. Honda and T. Murakami).

The presence of the acicular complex ferrite + Fe_2W in steels with 0·1 per cent. of carbon and 5 per cent. of tungsten proves that this limit must be extended to low percentages of tungsten.

¹ A. Portevin, *Comptes Rendus*, 1921, vol. clxxii. p. 445.

In addition to the foregoing there are to be observed, in these steels, white areas of ferrite (solid $\text{Fe-Fe}_2\text{W}$ solution) the proportions of which diminish as the carbon percentage increases, and a carbide (which, according to K. Honda and T. Murakami, is WC) either in visible particles more or less coalescent or forming part of a troostite readily stained by acid reagents.

Once obtained, this special acicular constituent persists even if these steels be subjected to fresh annealings at about 1000°C . On the other hand, by annealing at 1100° (and cooling for a period of $3\frac{1}{2}$ hours) the carbide can be made to disappear and only ferrite and the acicular complex remains in steels low in carbon (Fig. 4). The entire solubility curve of Fe_2W in the solid state requires to be extended in the direction of the low percentages of tungsten.

To sum up : in tungsten steels a structure comprising four constituents is encountered ; a tungstitic ferrite, a tungsten carbide, a tungstitic troostite, and a new constituent which is a complex ferrite + Fe_2W . This amounts, however, but to three phases : solid $\text{Fe-Fe}_2\text{W}$ solution, WC, and Fe_2W , which is compatible with the equilibrium of the Fe-W-C system.

II. MOLYBDENUM STEELS.

The author has succeeded in finding in molybdenum steels, annealed as previously described, a constituent presenting the same morphological characteristics and susceptibility to etching as the acicular complex just described in connection with tungsten steels. Instead, however, of occurring as it does in the steel containing 0.4 per cent. of carbon and 5 per cent. of tungsten, in masses regularly distributed and forming the interstitial packing between a network of carbon complex, this constituent is found in irregularly disseminated clusters in a ground mass very readily colourable by acid reagents and hence more highly carburised. These clusters are, moreover, visible to the naked eye owing to the considerable enlargement of the scale of the structural arrangement, resulting from the very slow cooling.

The appearances are identical. It is only necessary to compare Figs. 3 and 5, which show very fine needles distributed according to the Widmanstaetten structure, and colourable by sodium picrate (Figs. 5 and 6, Plate XIII.).

Our knowledge relating to the equilibrium of the iron-molybdenum system is confined actually to the hypothetical pseudo-binary diagram plotted by Lautsch and Tammann, which allows of the existence of a compound X, which forms slowly, but increases with the temperature attained. On the other hand, Vigouroux, basing his results on the analyses of the residues from etching with hydrochloric acid, concluded that four compounds were present, one of which was Fe_2Mo . The investigation, by chemical methods, of the constitution of alloys has, however, often proved fertile in putting forward compounds which have subsequently been found to have no real existence. In these circumstances, and taking into consideration the much smaller number of observations, it is not possible to draw definite conclusions as to the chemical nature of these acicular needles, which may be either an iron-molybdenum, or an iron-carbon molybdenum compound. Whichever they may be, the similarity between these structures in tungsten and in molybdenum steels has appeared to the author of interest to record, the more so as the presence of these constituents indicates a state of equilibrium more stable than that previously encountered.

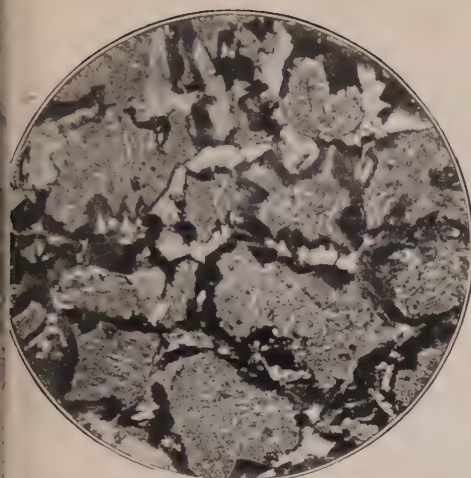


FIG. 1. Tungsten Steel (C=0.4; W=5.4%). Annealed and very slowly cooled. Etched for 1 min. with Benedick's reagent. $\times 30$.

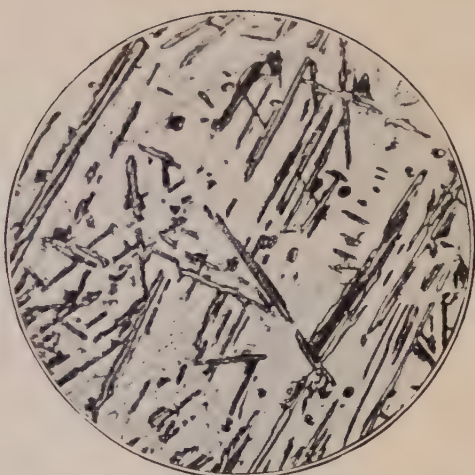


FIG. 2. Tungsten Steel (C=0.4; W=5.4%). Annealed and very slowly cooled. Etched for 1 min. with Benedick's reagent. $\times 870$.



FIG. 3. Tungsten Steel (C=0.4; W=5.4%). Annealed and very slowly cooled. Etched for 4 mins. with sodium picrate. $\times 200$.

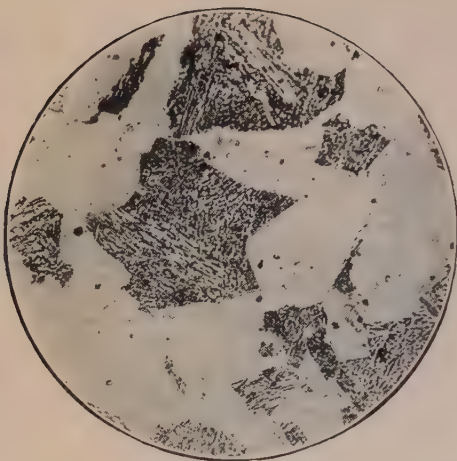


FIG. 4. Tungsten Steel ($C=0.1$; $W=5\%$). Annealed and very slowly cooled; then annealed again at 1100° and cooled for $3\frac{1}{2}$ hours. Etched for $2\frac{1}{2}$ mins. with Benedick's reagent. $\times 200$.

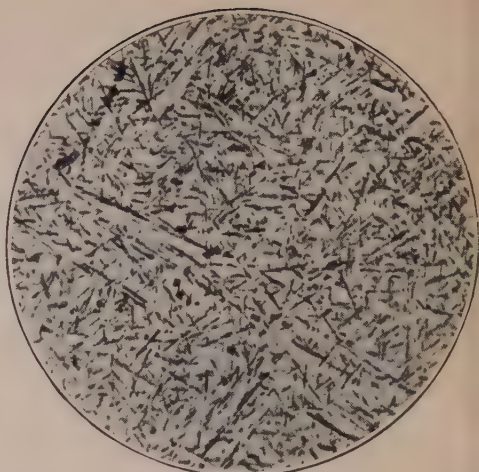


FIG 5. Molybdenum Steel ($C=0.5$; $Mo=1\%$). Annealed and very slowly cooled. Etched for 10 mins. with sodium picrate. $\times 200$

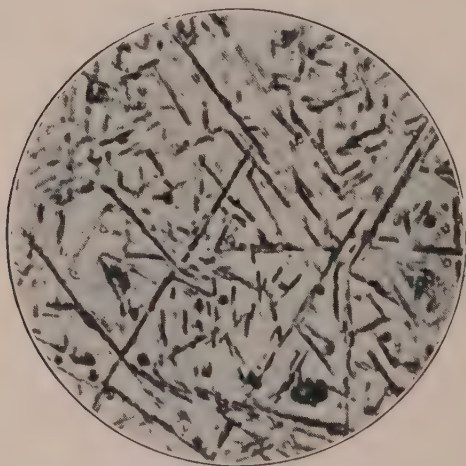


FIG. 6. Molybdenum Steel ($C=0.5$; $Mo=1\%$). Annealed and very slowly cooled. Etched for 10 mins. with sodium picrate. $\times 600$.

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CONTRIBUTIONS TO THE STUDY OF
COALESCENCE IN STEELS AND ITS
COMMERCIAL RESULTS.¹

BY ALBERT PORTEVIN AND VICTOR BERNARD (PARIS).

PART I.

FACTORS INFLUENCING THE PHENOMENA OF COALESCENCE.

General Considerations.—Coalescence is a universal phenomenon in alloys and consists of the fact that elements of structures of similar kinds, that is to say, belonging to the same phases, unite and agglomerate, thus giving rise to coarser elements. Besides this a very marked tendency may be observed, in the case of two or more phases, for the contours to become rounded, this leading to the assumption of the spherical form with its minimum of surface for a given volume, and so, in the case of the eutectic aggregates, to the globular, or spheroidal varieties.

This dual aspect of the phenomena, increase in the size of the elements of a particular phase and tendency towards the spherical state, is characteristic of the tendency towards structural equilibrium, in which the phases of a complex material, instead of being formed of elements mutually disseminated throughout an aggregate, occur in continuous and distinct masses respectively in contact with one another.

In mixtures of two phases coalescence takes place in the three following sets of conditions which, on examination, bring out the elementary factors of the phenomena, enumerated later.

1. *At Constant Temperatures.*—Here only the variations in the intersolubility of the structural elements come into play in terms of the radii of their curves, their state of deformation, and their rate of diffusion in the solid state. Hence arises the fundamental importance of the part played by the original dimensions of the particles of the complexus, and by the state of internal stress. The latter factor does not obtain at high temperatures, which remove the internal stresses.

¹ For discussion see pp. 138-139.

As the rates of diffusion and of solution increase with the temperature, coalescence will take place the more rapidly in proportion as the temperature is higher. The temperature and the length of time are the variables of the problem.

2. *At Falling Temperatures.*—To the foregoing factors are superadded¹ the influence of the crystalline germ-forms, the heterogeneity of solid solutions, the variation—with the temperature—of the solubility, the faculty of spontaneous crystallisation, and the linear rate of crystallisation. As the crystalline germ-forms disappear gradually with increasing temperature the phenomena evolved will depend upon the antecedent states besides which certain chemical elements present in minute proportions are able to play the part of catalytic agents in regard to the predominating chemical system. These latter influences are affected by the intervention of the following variables: chemical status and equilibrium diagram conditions, antecedent heat treatment (which may be characterised by the maximum temperature attained and the duration of heating), and rate of cooling, or, more correctly speaking, the law of cooling. On the other hand, the directive influence which the crystalline environment exercises over the shape assumed by the structural elements while being deposited, helps to counteract the tendency towards the spheroidal form² at alternating temperatures (that is to say, during the alternations of heating and cooling about an equilibrium line in the diagram). Here, in addition, the rate of solution at rising temperatures intervenes, as well as the size of the antecedent structural elements, and to the foregoing variables must be added the law of variations in temperature, and in particular the number and amplitude of the alternations undergone.

Results of the Influence of these Different Factors on the Steel.—These various factors lead to the agglomeration of the cementite of the steel in distinct rounded masses termed globular or spheroidal cementite. When, more particularly, this modification in shape affects the pearlite elements the latter is termed granular, or grained pearlite, to distinguish it from lamellar pearlite. This

¹ See A. Portevin, "Principles and General Phenomena relating to Crystallisation, Solidification, and Devitrification," *Revue Ingénieur*, 1921, vol. xxviii. p. 165.

² A. Portevin, *Revue de Métallurgie*, 1919, vol. xvi. p. 14.

term appears to the authors to tend to confuse the issue, since the expression granular or grained structure has long been employed by mineralogists and crystallographers to designate the conglomerates of juxtaposed grains of crystalline elements. It is thus a term applicable to every crystalline mass composed of more than a single crystal, and thus to all metals, all alloys, and all holo-crystalline rocks. Therefore, in order to describe the rounded globular form of the pearlite elements, the authors prefer in future to employ the term "globular pearlite" (in contradistinction to lamellar pearlite) instead of the term "granular pearlite," which they, in common with all other writers on the subject, have hitherto employed.

In steels with a low carbon content (< 0.5 per cent.) the coalescence of the cementite reveals itself by the pearlite areas becoming bounded by a belt of partly formed cementite with the ragged edges which Osmond termed "atolls," from the analogy presented by these irregularly shaped rings of cementite with the coral islets so named. These forms do not, however, occur in the eutectic and hypereutectic steels which the authors are about to deal with.

The transformation of cementite lamellæ into globules involves an intermediate stage where strands of spherules occur. This is the "necklace" pearlite described by Benedicks¹ (who observed the phenomenon in a grey pig iron), which is similarly encountered in the very long and thin lamellæ of cementite in a high carbon steel superheated after a preliminary quenching (Hanemann and Morawe). An example of this appearance is given in Micrograph No. 2 (Plate XIV.).

If now we take the case of the hypereutectic carbon steels we shall see that we have to distinguish between :

1. The coalescence of the proeutectic cementite in the temperature zone comprised between A_{cm} and A_1 , that is to say, in the region $Fe_3C +$ the solid solution of γ -iron-carbon, the solubility of the cementite varying considerably with the temperature in this region ; and

2. The coalescence of the eutectic or pearlite (?) cementite at temperatures below A_1 , that is to say, in the region α iron + Fe_3C , the solubility of the cementite being in this case practically

¹ *Revue de Métallurgie*, 1909, vol. vi. p. 567.

nil and independent of the temperature.¹ This distinction drawn, the authors will now investigate the influence, on the coalescence of cementite, of various elemental factors which are the results of the known general laws of solubility and of crystallisation, and which may be enumerated by passing in review the experimental researches on the formation of globular cementite by Hanemann, Morawe, and Lindt, by Howe, Levy, Whiteley, Honda, and Saito, by the present authors, and by still earlier observers such as Stead, Arnold, Osmond, Lange, Law, Ischewsky, and Belaiew.²

From the general remarks made it is easy to see that the effect of the different factors is entirely different both in kind and degree according as the temperature zone is above or below A1, so that by limiting consideration to those only which are beneficial and appreciable in each instance it is possible to reduce their incidence to those summarised in the following table :

I. For one and the same Steel.

(a) Above A1.

1. Rate of cooling.
2. Temperature and duration of initial heating.
3. Temperature alternations about A1.

(b) Below A1.

4. Temperature and duration of maintenance at this temperature.
5. Previous mechanical working.
6. Original fineness of the cementite elements (troostitic or sorbitic states).

II. For Different Steels (the preceding factors remaining equal).

7. Carbon percentage.
8. Presence of elements other than carbon, such as, more particularly, chromium, tungsten, and molybdenum.

¹ In reality the solubility cannot be actually nil: it is exceedingly feeble, and insufficient for representation on the scale of the equilibrium diagram. That solubility exists is a deduction from phase law, and from the very fact of the existence of coalescence phenomena.

² H. M. Howe and A. G. Levy, *Transactions of the American Institute of Mining Engineers*, October 1912; *Journal of the Iron and Steel Institute*, 1916, No. II. p. 210.

Hanemann and Morawe, *Stahl und Eisen*, 1913, vol. xxxiii. p. 1350; *Revue de Métallurgie*, 1914, vol. xi. p. 451.

Hanemann and Lindt, *Stahl und Eisen*, 1913, vol. xxxiii. p. 551; *Revue de Métallurgie*, 1914, vol. xi. p. 26.

A. Portevin, *Revue de Métallurgie*, 1913, vol. x. p. 667.

A. Portevin and V. Bernard, *Journal of the Iron and Steel Institute*, 1914, No. II. p. 204; *Revue de Métallurgie*, 1915, vol. xii. p. 147.

A. L. Babochine, *Rev. Soc. Russe Mét.*, 1915, vol. iii. p. 561; *Revue de Métallurgie*, 1917, vol. xiv. p. 81.

N. G. Ilyne, *Rev. Soc. Russe Mét.*, 1915, vol. iii. p. 488.

J. H. Whiteley, *Journal of the Iron and Steel Institute*, 1918, No. I. p. 353.

K. Honda and S. Saito, *Sc. Rep. Tohoku Imp. Univ.*, 1920, vol. ix. p. 311.

J. E. Stead, *Metallographist*, 1898, vol. i. p. 329; *Proceedings of the Institution*

The particulars relating to the part played by these various factors are not always in agreement and are sometimes even contradictory, according to their authors. This, in the present authors' opinions, arises from the fact that, consciously or unconsciously, certain of these factors have been overlooked by some of the observers whose attention has been too exclusively devoted to those which, in their opinion, had the greatest influence on the result.

It would appear necessary therefore to take into consideration the whole of these factors, and that this course is indeed indispensable in order to take into purview the totality of the conditions under which the coalescence of cementite can be either stimulated or destroyed. The importance of this operation will be seen in the second part of the present paper, where the effects of coalescence on the properties and heat treatment of steels are investigated. The authors will therefore briefly collate the various data actually in their possession, adding thereto the fresh results of their own personal observations.

1. *Rate of Cooling*.—Slow cooling favours coalescence within the zone of transformation Acm-A1, and during the passage through A1, that is to say, when the solubility of the cementite varies. To lower the rate of cooling is equivalent to prolonging the period of annealing at different temperatures (Howe and Levy). This equivalence persists, obviously, below A1; but as will be seen later very prolonged periods of annealing are required to cause appreciable phenomena within this zone, so that the effect of the slowness of cooling thus becomes practically negligible, particularly if it be practically comparable with the slowness of cooling while passing through A1.

In regard to the latter consideration, Hanemann and Morawe have given the rate of 2° per minute as the upper limit of the

of *Mechanical Engineers*, 1899, p. 73; *Journal of the Iron and Steel Institute*, 1902, No. I. p. 172; *Journal of the Society of Chemical Industry*, 1903, vol. xxii. p. 343.

Arnold, *Journal of the Iron and Steel Institute*, 1898, No. II. p. 185; 1901, No. I. p. 180; *Metallographist*, 1902, vol. v. p. 2.

Lange, *Metallographist*, 1903, vol. vi. p. 9.

Osmond, *Revue de Métallurgie*, 1904, vol. i. p. 349.

Goerens, *Métallurgie*, 1907, vol. iv. p. 182.

Ischewsky, *Ibid.*, 1911, vol. viii. p. 701.

N. T. Belaiew, *Ibid.*, pp. 449, 493, 699 (citing Bréant, Anossow, and Sawin), *Journ. Soc. Mét. Russe*, 1914, vol. ii. p. 445.

formation of globular pearlite in a eutectic steel: in hypereutectic steels this globular pearlite is even more easily obtained, that is to say, with higher rates of cooling, owing to the part played by the pro-eutectoid cementite in retarding the action, so that in the case of steels containing 1.3 per cent. of carbon and over, this effect is so intense that it is necessary to have recourse to air cooling on small samples in order to obtain lamellar pearlite. Thus hypereutectic steels annealed under ordinary conditions possess, as a general rule, a granular structure.¹ This rule, however, does not take into account the influence of the original heating temperature, and if the latter has been high enough to lead to the complete solution of the cementite these conclusions are no longer valid. This effect of the original temperature will be discussed later; the authors will limit themselves, in this connection, to pointing out that if the rate of speed during the passage of A1 were the only determinant all eutectic or hypereutectic steel ingots in their freshly cast state would have a globular pearlite structure, whereas, on the contrary, the pearlite, as is well known, is, in such ingots, lamellar.

The various appearances resulting from the coalescence of pro-eutectic cementite on annealing may easily be observed in a single experiment by starting, as the authors have done, with a highly cemented sample which allows of the simultaneous observation of the whole series of structure changes. In the original sample, the outer and highly carburised zone shows cementite in coarse needles (Micrograph No. 1, Plate XIV., Widmanstaetten structure) which changes gradually to a cellular redistribution owing to the decrease, with the diminishing carbon content, of the dimensions of the original grains of the solid γ -iron-carbon solution in which the cementite has originated.² If a steel be subjected to an annealing at 900° (annealing for four hours followed by a cooling extending over seven and a half hours) it is found that the following sequence of appearances occurs:

1. The needles (in reality, plates) of cementite are broken

¹ See the examples given on Plate XLVII., Figs. 270 to 273, of the "Précis de Métallographie," by L. Guillet and A. Portevin (Paris, Dunod, 1914).

² It is known that, heating conditions being equal, the size of the grain of the solid γ -iron-carbon solution increases with the carbon content (Howe), and that the intergranular distribution (Widmanstaetten structure) is the more readily attained, under equal cooling conditions, in proportion as the initial grains are more fully developed.

up into elements whose edges are rounded and whose threadlike arrangement reveals their origin.

2. The network breaks up similarly into elements tending toward the globular form, but the differential distribution of which similarly reveals the origin.

3. In the less highly carburised but nevertheless still hyper-eutectic areas the network is not appreciably altered (Micrograph No. 4, Plate XV.).

2. *Temperature and Duration of Heating above A1.*—The heating of a hypereutectic steel to above A_{cm} , that is to say, within the region of solid solution, leads to the solution of the cementite, and this result is the more speedily attained in proportion as the temperature is higher, so that increase in the temperature and duration of heating lead to the disappearance of the free cementite and of the ultra-microscopic particles which tend to act as a lag on the crystallisation, and to secure homogenisation in the carbon content of the solid solution. These causes impede therefore the ultimate coalescence of the cementite,¹ a fact of which the ingots as fresh cast, and referred to earlier, afford evidence.²

In further confirmation of these facts may be adduced the instances of case-hardened irons and steels maintained for long periods at high temperatures, which, despite exceedingly prolonged cooling (extending over several days), show, side by side with cementite coalesced into elements visible to the naked eye, pearlite showing, here and there, a lamellar form, but in highly developed plates recognisable under very small magnifications.

The authors have likewise observed that by heating the sample of case-hardened steel referred to above up to 1300° or 1400° and letting it cool very slowly, the whole of the pearlite remains lamellar, whilst the point A1 is being passed at a rate of 0.3° per minute, which is very different from the limits assigned by Hanemann and Morawe. Numerous other instances could be quoted, but these would appear to suffice. K. Honda and S. Saito have heated a series of steels with variable percentages

¹ These causes are the same as those which, for the same reasons, retard the critical rate of hardening.

² Other examples of this micrography of lamellar pearlite in steel ingots as cast will be found in Dalby's investigations. *Engineering*, 1917, April 6, "Strength and Inner Structure of Mild Steel."

of carbon by maintaining them for twenty minutes at various temperatures and then cooling them slowly (without, however, stating the rates of cooling). They have observed in hyper-eutectic steels that coalescence of the cementite occurs at all temperatures comprised between A_{c1} and a temperature which increases with the percentage of carbon in the following way :

Percentage of carbon	0.80	1.20	1.59 (and over)
Highest temperature of coalescence.	750°	780°	850°

Above the latter limits the lamellar pearlite reappears on cooling.

The influence of the temperature and the duration of heating on the coalescence during cooling often appear to be unknown in industrial practice, particularly after a softening annealing for ball-bearing steels containing 1 per cent. of carbon and 1 to 2 per cent. of chromium, the treatment of which should lead to the production of globular cementite. It might sometimes be thought that the end might be sought by intensifying both the conditions accompanying annealing, temperature of heating and slowness of cooling, and thus the authors have observed at certain works the practice of heating up to 900° for six to seven hours, followed by a cooling extended over sixty hours before reaching 400° to 500°. The results have been deplorable, whereas a heating of six to fifteen hours at only 750°, followed by cooling, over a period of about ten hours to 500° would have been much better.

From the influence of these two factors emerges, as a direct consequence, the influence of the rate of heating. Coalescence (and therefore the resultant softening of the steel) is a function of the rate of heating, particularly in the region immediately below A_{c1} , as has been found in the case of the ball-bearing steels referred to.

3. *Alternations of Temperature during the Passage of A_1 .*—This provides one of the best modes of securing the coalescence of the cementite. During the periods of heating the tiny particles of cementite disappear, both because of their minute dimensions and their greater solubility, while, during the periods of cooling, the dissolved cementite precipitates on the residual particles, the dimensions of which grow accordingly. Osmond ¹ had already pointed out this method and drawn attention to the analogy it

¹ See also Ischewsky, *loc. cit.*

presents with that employed to obtain large crystals from saline solutions. In both instances the phenomena result from the same mechanism.

Micrograph No. 5 (Plate XVI.) shows the result of three temperature alternations between 750° and 700° on the steel, the initial state of which is shown in No. 1. It will be seen that coalescence is much more pronounced than in No. 2, although there may still be distinguished the arrangement of the original needles of cementite. In Micrograph No. 6, which represents a less carburised zone subjected to the same treatment, every trace of the original structure has disappeared.

It may be said that every alternation of temperature about A1 diminishes the number and increases the size of the cementite elements.

4. *Temperature and Duration of Heating below A1.*—Opinions are divided as to the influence of these two factors. Of the different observers, one group (Goerens, Hanemann and Morawe, Howe and Levy, &c.) agree that there is, in all instances, coalescence of cementite as the result of prolonged heating below A1, the phenomena taking place the more rapidly in proportion as the temperature—while still remaining below A1—is higher. On the other hand, Honda and Saito consider that the coalescence of lamellar cementite can never occur unless Ac1 is reached, but that, if sorbite be present (if, that is, a hardened sample be taken) cementite coalescence occurs. These divergent views arise, in the authors' opinion, from the differences in the experimental conditions and the difficulty of accurately determining the annealing temperature in relation to A1. The latter point is known only by its manifestations Ac1 and Ar1, which occur respectively on heating and on cooling, and it depends on the rates at which the temperature varies, so that if Ac1 be approached as closely as possible in order to stimulate the phenomenon of coalescence there is a danger of exceeding it. Now it is beyond doubt that one of the most efficacious means of obtaining globular pearlite is to effect the A1 transformation slowly during cooling, and that there is therefore a danger, on endeavouring to maintain a sample in the neighbourhood of this point, of this mode of action, and of alternations of temperature (which are eminently favourable to the occurrence of coalescence) taking place.

The negative results (those of Honda and Saito) relate to periods of heating extending for twenty minutes up to twelve hours, that is to say, relatively short ones, whereas the positive results have been deduced from greatly prolonged periods of heating. Hanemann and Morawe, for instance, report the breaking up of the cementite lamellæ after annealing for thirty-five hours at 685° and their complete disappearance after being maintained for 1062 hours at this temperature. It is not possible, therefore, to compare these experimental methods, and the coalescence of lamellar pearlite below Acl ought to be accepted as a fact, if it be allowed that such greatly prolonged heating could have been carried out in a platinum resistance furnace, in which rigorous control of the temperature (unless an absolutely constant current supply be available) is an exceedingly delicate matter, without the Acl point having been exceeded. The authors have carried out analogous experiments on hypereutectic steels with well-developed pearlite lamellæ, unworked, and kept for ten, thirty, and fifty hours at 700° in a salt-bath furnace. Coalescence is but feebly marked, and well-formed lamellæ are found persisting even after these various treatments (Fig. 7). On the other hand, on eutectic and hypoeutectic steels as rolled, and heated for fifty hours at 700° in salt-baths, the authors¹ have obtained complete disappearance of the lamellar structure. They will deduce their conclusions after having examined the influence of the remaining factors.

5 and 6. *Preliminary Mechanical Treatment ; State of Division of the Cementite Elements ; Effect of Forging.*—We have seen that the coalescence of the cementite into large plates takes place by a preliminary breaking down whereby the fragments subsequently take a globular form while remaining arranged in strands. The process will therefore be facilitated if this preliminary breaking up of the lamellæ of the proeutectic and eutectic cementite be effected by mechanical means or even simply by deforming them when hot (forging) or when cold (cold-working).

The experiments of J. H. Whiteley are peculiarly illustrative of the effect of cold-working on the formation of globular pearlite. This cold-working was carried out by hammering down, under

¹ A. Portevin and V. Bernard, *Journal of the Iron and Steel Institute*, 1914, No. II, p. 204.

a steam-hammer, steel bars so as to reduce their diameter by one-half, while taking care that the temperature attained during the operation did not exceed 100° . His conclusions can be summarised as follows: Annealing after cold-working has the effect of rapidly breaking up the lamellæ of cementite and pearlite into spheroid particles. The change commences at about 500° (that is, at about the temperature noted by Goerens as that of the disappearance of cold-work effects in steel) and continues with increasing speed as the temperature rises. At 680° the disappearance of the lamellar pearlite can be completed in less than two hours, even in a eutectoid steel in which the lamellæ are exceedingly thin. About four hours' heating are required for the very coarse pearlite, whereas, with a steel not previously cold-worked, this result cannot be attained under several days' heating.

The effect of annealing after cold-working becomes clearly manifest if the modifications of structure resulting from cold rolling and successive annealings on the same 1.2 per cent. carbon steel sheet be examined, as was done by Hanemann and Lindt. It was found that each annealing following a rolling accentuated the coalescence of the cementite. The steel, which after the first annealing showed a structure of lamellar pearlite and sorbite, consisted entirely of globular pearlite after two rollings and two reheatings. The cementite globules continued to grow as the treatments were persisted in. Whiteley was unable, after the closest examination, to detect the slightest trace, after cold-working, of any rupture of the lamellæ of pearlite cementite, and recalls Howe and Levy's experience of the very great flexibility of these lamellæ in their experiments on the plastic deformation of pearlite, a flexibility which is not surprising in lamellæ so exceedingly thin, inasmuch as the elastic deformation of bending increases inversely as the cube of the thickness. Permanent deformation and even, as Professor H. Le Chatelier has pointed out, elastic deformation, suffice to vary the solubility of the cementite, and therefore, in accordance with the general views referred to in the introductory paragraphs of the present paper, its reaction on the phenomenon of coalescence. It may, in addition, be added that even if the deformation of the cementite lamellæ be purely elastic that of the ferrite must of necessity be permanent in any plastic

deformation of the whole. The cold-working of the cementite alters the mutual intersolubility of the complex, ferrite-cementite, which is the factor to bear in mind.

It is, similarly to the variation in solubility—a function of the radius of the curve—that the influence on coalescence of the fineness of the cementite elements is to be attributed. The spheroidisation of the cementite is distinctly intensified if troostite or sorbite be previously present, and if, therefore, the steel has been previously hardened.¹ On this point all the observations agree; the result is completely comparable with that obtained by preliminary deformation. It is to this double influence of the plastic deformation and the fineness of structure that must be attributed the greater aptitude towards coalescence which has been observed and recorded when untreated forged steels are taken. In addition to the forging the air cooling which follows leads, generally speaking, to the partial formation of troostite.

This acceleration of coalescence by the influence of forging is such that it reveals itself on examination by variations in hardness, even after relatively very short periods of heating, in the case of steels in which coalescence is difficult, such as steels with 1 per cent. of carbon and 1 to 2 per cent. of chromium. The following examples are taken from the results obtained on a steel of this composition, as forged, and kept, for ten minutes only, at different temperatures, the heating being followed by oil immersion :

		Acl.					
Temperature of heating	.	500°	600°	700°	725°	750°	775°
Brinell hardness	.	361	364	340	315	444	652

The examination of the influence of these different factors now enables conclusions to be drawn as to the part played by heatings to temperatures below A1.

1. Starting with steels previously cold-worked, forged, or quenched, coalescence becomes manifest for heatings which do not exceed A1, and is the more pronounced in proportion as the temperature of heating is higher and the duration more

¹ It is necessary to point out in this connection the method of operating, often attended with success, for softening the self-hardening nickel-chromium steels, which consists of giving an oil-quenching previous to the ordinary heating up to just below Acl.

prolonged. It is not really appreciable until the Ac1 temperature is approached.

2. Starting with annealed steels containing lamellar pearlite, coalescence below A1 is only perceptible in the case of extremely prolonged periods of heating, so that in such instances the influence of this factor may be disregarded.

In any case the rate of cooling below A1 has practically no effect, with the result that a coalescence treatment can be ended by rapid cooling once the temperature has fallen below Ar1. The only consideration that need intervene in the choice of the rate of cooling is, as pointed out by Howe and Levy, that of the residual internal stresses.

7 and 8. *Chemical Composition of the Steel (percentage in Carbon and in other Elements).*—The programme of experiments undertaken by the authors with a view to ascertaining the influence of the chemical composition of steel upon the phenomena of coalescence has only been begun, having been interrupted in 1914 and the tests not having been recommenced since. While awaiting the opportunity of collating data on this subject the authors must remain content to recall the following points:

The difficulty of effecting coalescence of the cementite is greatest in the case of the eutectic composition.¹ In the case of the hypereutectic steels the readiness to coalesce increases with the carbon percentage, and this phenomenon is a constant in all annealings of such steels carried out within the range of transformation.

Low percentages of chromium and of tungsten render the coalescence of steels containing 1.0 to 1.2 per cent. of carbon more difficult. This is well known in connection with ball-bearing steels. A steel containing 1.2 per cent. of carbon, 0.5 per cent. of tungsten, and 0.5 per cent. of chromium displayed a barely appreciable degree of coalescence when subjected to a treatment which had caused complete coalescence in a tool steel with 0.98 per cent. of carbon. The Brinell hardness remained 220 in the first instance, whereas in the second it fell to 136.

On the other hand higher percentages of chromium, tungsten, and molybdenum cause complete coalescence of the carbon.

¹ Howe and Levy. This fact may be co-ordinated with that of the minimum critical rate of hardening (Portevin and Garvin), as they both have the same origin, the reduction in the retarding effect on the crystallisation of the cementite.

The necessary percentages to ensure this result diminish, for a given treatment, with the carbon percentage. All the carbon then occurs in the globular form observed by Osmond in chromium steels, and presents the micrographic appearance termed "double carbide," which is a structure identical with that of coalesced hypereutectic steels.

Having thus a knowledge of the various factors which influence the formation of globular cementite, their relative importance and the direction in which they act, it is easy to see how and to what extent it is possible in practice to obtain or to destroy coalescence of cementite in any particular instance, by means of certain tests, the sequence of which may be conceived from the particulars so obtained. Indeed the task is one which can be entrusted to any trained operator.

PART II.

INFLUENCE OF THE COALESCENCE OF CEMENTITE ON THE PROPERTIES AND HEAT TREATMENT OF HYPEREUTECTIC STEELS.

The inquiry will now be directed briefly and successively to the influence on coalescence of :

1. *The hardness*, in order to obtain the maximum softness required in a steel.
2. *The malleability, in the cold*, from the point of view, more particularly, of the die-stamping of sheets and the drawing of tubes.
3. *The surface finish on machining*, in the case of precision parts.
4. *The chemical properties*, which will consist merely of a recapitulation of the results obtained by other observers.
5. *The heat treatment*, by showing the reflex action of the original coalescence on the results of quenching.

It is the last-named section to which attention will be more particularly directed, seeing that, so far as the authors are aware, hardly anything has hitherto been published respecting the experimental numerical data relating to this subject except that

to which they have already given publicity.¹ On the other hand, as regards the effect of coalescence on the mechanical properties, reference can be made to the works previously quoted, and in particular to that of Belaiew, Howe and Levy, Hanemann, Morawe, and Lindt, and mere mention will be made of the present authors' own results.

1. *Influence of the Hardness.*—Although in the case of many steels such softening as is required for their easy and economic machining can be sufficiently obtained by an annealing which brings the pearlite to the lamellar or even sorbitic condition, for certain steels, specifically hard owing to their chemical composition, it is necessary to obtain the cementite in the globular state in order sufficiently to reduce the hardness of the material to enable it to be machined without too great difficulty. The annealing treatment in such cases should not lead only to the physico-chemical state of equilibrium characterised by the mixture $\alpha\text{Fe} + \text{Fe}_3\text{C}$, but should further lead to the obtaining of the state of structural equilibrium corresponding with the greatest possible degree of separation between the two phases constituting this mixture. This is an annealing for structure, a coalescing anneal to which Howe and Levy have applied the term "divorcing annealing." Such instances occur industrially in, more particularly :

(1) Hypereutectic carbon tool steels with or without chromium and tungsten.

(2) Ball-bearing steels with 1.0 per cent. of carbon and 1.0 to 2.0 per cent. of chromium, for which a softening corresponding with a Brinell number of 187 to 170 is required (imprint diameter of 4.4 to 4.6 millimetres with a 10-millimetre ball and a pressure of 3000 kilogrammes). So low a hardness cannot be obtained in a steel of such a composition except by causing the cementite to coalesce.

The resultant softening is naturally a function of the degree of coalescence acquired by the cementite elements. The more marked the ferrite-cementite separation, or, in other words, the more the cementite globules are developed, the lower the hardness.

¹ A. Portevin and V. Bernard, *Journal of the Iron and Steel Institute*, 1914, No. II. p. 204. Quite recently Dejean (*Technique Moderne*, 1920, vol. xii. p. 403), dealing with the subject, confines himself to instancing this effect of coalescence on the hardening, merely as an inductive result of industrial practice.

It would obviously be of great interest to be able to define numerically the average size of the cementite elements, so as to be able to define the degree of coalescence attained in a given steel containing a known proportion of cementite. An attempt might be made, with this object, to count the globules per unit volume of steel. By ascertaining the number, n , of elements per unit of surface, in a micrographic preparation, the number per unit of volume would be given by $N = n^{\frac{3}{2}}$. In the micrographic estimation, however, it would be necessary to have recourse to very high magnifications ($\times 1000$) in order to be able to count the elements visible in the globular pearlite, which would only be possible in a reduced section, and this would so falsify the result that the probable error would increase enormously. For the moment the authors cannot help regarding such a process of estimation as of questionable value. It appears to them better, for the attainment of the end in view, indirectly to estimate the degree of coalescence by measuring the physical or mechanical property with which it corresponds. For this purpose the degree of coalescence attained will be regarded as defined by the hardness attained, as compared with the hardness of the same steel when the pearlite is in the lamellar condition.

In carbon tool steels the maximum softening the authors have been able to produce by industrially practicable treatments corresponds with the following hardness characteristics, the steel in question having 0.98 per cent. of carbon.

	Diameter of Ball Impression. (10-mm. ball; load, 3000 kgms.)	Brinell No. Δ .	Value of $R = 0.34 \Delta$.
In the globular state . .	5.1 mm.	137	47 kg./mm. ²
In the lamellar state . .	3.75 "	262	89 "

The micrographic appearance in both states is given, at a magnification of 1200 diameters, in Nos. 8 and 9 (Plates XV., XVI.).

It has thus been possible, simply by influencing the coalescence of the cementite, to reduce the original Brinell hardness and the breaking stress by 50 per cent. These results have been obtained by the following heat treatments.

(1) Coalescing, or structural anneal; heating for twenty-five hours at 750° ; cooling¹ at, on an average, 5° per hour from 750° to 650° .

(2) Regenerating, or structural-refining anneal to induce the globular condition to transform to the lamellar condition. After several tests the following method of annealing was adopted: heating for three hours at 850° followed by air cooling (the bars were 8 to 25 millimetres in diameter).

It was from samples thus prepared that the investigation of the influence of coalescence on the heat treatment (described later) was carried out.

Note relating to the Brinell Hardness of Cementite.—The Brinell hardness of cementite is not known. It is not even possible to ascertain it directly, by any of the usual methods, because of its extreme brittleness.² The investigation, however, of the products of coalescence furnish a method of ascertaining it indirectly by extrapolation, from the following considerations:

It is known that, in the binary alloys formed of a mixture, in variable proportions, of two similar constituents, the hardness is practically a linear function of the composition when the structural elements remain constant in size. Therefore, if the proportions of the constituents remain constant the hardness will tend to increase as the fineness of the structural elements.

The iron-carbon alloys in the annealed state consist of two phases, Fe_x and Fe_3C , intermingled, but the structural elements of which these phases are composed may vary very considerably in size according as they do or do not form part of the eutectic pearlite in its lamellar form. This lamellar pearlite forms a definite aggregate with 9 per cent. of carbon and a Brinell hardness in the neighbourhood of 250.

According to the rule just enunciated, the Brinell hardness of iron-carbon alloys, starting with pure iron and going up to 6.60 per cent. of cementite in the annealed state can be represented schematically (in terms of the carbon percentages) as follows (Fig. 1).

(1) For the products containing pearlite in the lamellar state,

¹ This was applied, in ordinary practice, to a mass of metal weighing 5 tons.

² Its hardness on the Mohs scale is similarly unknown, the values given varying, according to the method of testing, up to 100 per cent.

by two straight lines, FP and PC, connecting the points indicative of the hardness of pure iron (point F), of lamellar pearlite (point P), and of the cementite (point C).

(2) For the coalesced products in such a manner as to connect all the cementite elements in globular form, and of the same order of size, by a straight line of minimum hardness, FC.

(3) For the products containing the whole of their carbon in the sorbitic state by an ill-defined curve, FSC, relating to the maximum hardness in the annealed state.

The hardness in the annealed state can therefore display

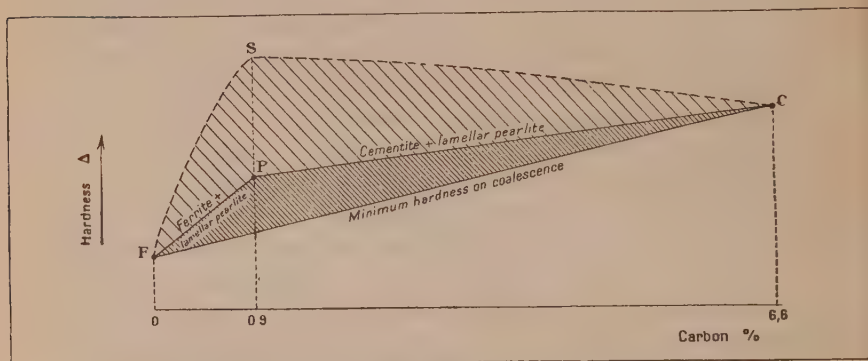


FIG. 1. Schematic Representation of Brinell Hardness.

the whole of the values comprised within the field FSCF, according to the carbon percentage and the state of division of the structural elements, and the hardness of the cementite can therefore be ascertained by either of two methods :

(1) By plotting the points of the line PC of the hardness of the hypereutectic products containing pearlite exclusively in the lamellar conditions, a condition extremely difficult to realise in the case of cast iron as either sorbite and troostite, or globular pearlite, are always intermixed with the lamellar pearlite.

(2) By plotting the points of the line FC of minimum hardness for various steels and cast irons, the minimum hardness of which has been estimated by their coalescence.

The latter process is practicable. By taking the only value quoted, that for the steel containing 0.98 per cent. of carbon, we arrive at a result of about 400 for the Brinell hardness of

cementite, but, naturally, in order to attain a reasonably accurate result, a whole series of points ought to be determined along the line FC at regular intervals up to about 5 per cent. of carbon.

2. *Influence on the Malleability in the Cold.*—As coalescence leads to a lowering of the apparent elastic limit and an increase in the elongation prior to fracture it facilitates the deformation of the metal, a result of great value in operations where this property is sought, as in the die-stamping of sheet metal and in tube-drawing.¹ Indeed, the effect of all such methods of manufacture as comprise alternations of cold-working and annealing is, as has already been seen, to stimulate granulation of the cementite if the heat treatment be rationally carried out. The authors have been able to ascertain, in connection with difficulties encountered, in the manufacture of war materials, from the stamping of certain sheets, and by means of micrographic examination, that the sheets giving unsatisfactory results possessed a structure more or less partly lamellar (sheets of 3 millimetres thick).

Comparative tensile tests carried out on the same steels in the globular and lamellar conditions respectively (the latter being obtained by appropriate annealing, have given the following figures for the mechanical properties :

Samples.	State.	R. (kg./mm. ²).	E. (kg./mm. ²).	Elongation per Cent.
I.	Globular	38·2	21·2	32·3
	Lamellar	43·3	28·2	30·2
II.	Globular	39·6	21·3	33·8
	Lamellar	42·1	28·6	32·0
III.	Globular	37·6	22·6	33·5
	Lamellar	41·7	28·2	33·0
IV.	Globular	43·2	23·0	32·0
	Lamellar	46·9	30·0	29·0

These results show that the most marked differences occur in the comparative properties of the same sheet, particularly as regards the elastic properties. This leads to the conclusion

¹ There may be recalled, in this connection, the properties of damascene steel (Belaiew); the influence of coalescence on the increase in the number of alternating areas prior to rupture in steel wire (Hanemann and Lindt), and the malleability of certain thin strands of high carbon and coalesced steels described by Hanemann and Morawe.

that the advantages possessed by using sheets with a globular structure for die-stamping reside chiefly in the fact that the work required to effect a given deformation (such as OD, Fig. 2) is distinctly lower than that which would be necessary in the case of a sheet, the structure of which was lamellar. Previously it might, *a priori*, have been thought that the advantage of using such sheets was that their coefficient of elongation was so much greater that more work could be put upon them without risk of cracking. An examination of Fig. 2 also shows that in the case of the sheet with a globular structure the margin of safety between

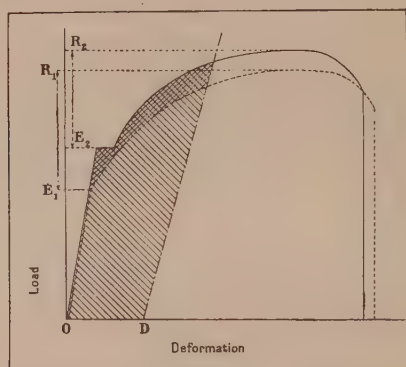


FIG. 2.

the elastic limit and the breaking stress is larger than it is in the case of those with a lamellar structure (compare the differences between the ordinates E_1R_1 and E_2R_2).

3. *Influence of the Surface Finish after Machining.*—The globular structure would appear to be the normal structure for eutectic and hypereutectic carbon tool steels, owing to the facilities they offer for machining. The authors have, however, had occasion to note an instance wherein this structure required to be destroyed, by means of an appropriate anneal, in order to give workshop satisfaction. It was a case of making screw plugs of great accuracy. When certain steels were used the faces of the threads were roughened to an extent incompatible with the degree of finish required, whereas with other bars of the same steel the faces of the threads were perfectly smooth. The microstructure of

the steels giving the defective threading differs very considerably from that of bars giving the proper thread finish, as may be seen in micrographs. This, then, was a case where the globular structure gave rise to difficulties in machining, these difficulties being surmounted by destroying this structure by annealing at 850° followed by air cooling. After this treatment the bars reverted to the lamellar state, and the appearance of the threads became satisfactory.

4. *Influence on the Chemical Properties.*—Coalescence, by modifying the shape and size of the structural elements, reacts on the susceptibility of the steel to chemical reagents. No experiments have been made by the authors in this connection, and they will confine themselves to recalling the experiments of Whiteley and of Hanemann and Lindt. The latter showed that coalescence causes the sulphuric acid solubility of steel to decrease and the former has shown that the values found by the Eggertz colour carbon test are considerably raised by coalescence.

5. *Influence on the Heat Treatments.*—Coalescence in steels is, as has been said, a result of the unequal intersolubility of the various structural elements of the complex, $\alpha\text{Fe} + \text{Fe}_3\text{C}$. As, therefore, the phenomenon is a manifestation of a tendency towards a state of structural equilibrium, it ought to follow that the intersolubility of the structural elements as a whole will diminish and tend towards a minimum. Besides this, and without bringing into consideration the variation in solubility resulting from the modification of the radius of curvature, the rate of mutual intersolubility of the ferrite and of the cementite diminishes owing to the reduction of the contact surfaces.¹ For these different reasons the dissolution of the carbide on heating will be more difficult to obtain in these coalesced steels. This is of extreme importance from the point of view of hardening as the heat treatments thus appear to be functions not only of the chemical composition of the steel, but also of its initial structural state, and therefore of its previous heat treatment.

The authors have already shown² that in order to obtain

¹ If a lamella of cementite of e thickness and $l \times l$ dimensions splits up into n spheres of equivalent volume, the variation in the resultant surface is diminished in the ratio: $\frac{s}{S} = 2.4 \left(n \frac{e^2}{l^2} \right)^{\frac{1}{3}}$.

² *Journal of the Iron and Steel Institute*, 1914, No. II. p. 204.

the same mechanical results with the same hardening treatment, it is necessary notably to prolong the period of heating in the case of steels already coalesced. They propose, on this occasion, to examine once again the influence of coalescence on the solution of iron carbide, on heating, by comparing one and the same steel in the globular state, and in the lamellar state. With this object they have had recourse to the following methods :

(1) Direct methods by the quantitative investigation of the curves of heating and cooling plotted by the methods in use for the determination of the critical points of steel, and using, more particularly, the thermal and differential dilatometrical methods.

(2) Indirect processes, by comparing the effects of heat treatments on the same steel in two different structural states, globular and lamellar, a comparison carried out in respect of their hardness, microstructure, electrical resistance, and magnetic properties.

(a) *Thermal Method*.—As it was a question of bringing into evidence very slight variations in the solubility of the carbide, the Roberts-Austen differential method was adopted. As is well known, in the case of these differential thermal curves the amplitude of the isothermal anomaly, due to the A1 transformation, can serve as a measure of the amount of heat evolved or absorbed in this transformation,¹ and therefore, as in the present instance, of the amount of carbide taken into solution or liberated therefrom. In order, however, that this method may lend itself to quantitative estimation it is necessary to eliminate a series of causes of error and of experimental difficulties, and this the authors have done by adopting the arrangements they have already described elsewhere.² They have, besides, in order to ensure the comparability of the thermal conditions, limited themselves to the examination of the effect of successive heatings on the same sample, initially coalesced, without the slightest derangement of the differential apparatus. Despite all these precautions the thermal method has only yielded very minute differences, and has not therefore commended itself to the authors as a suitable method to bring out variations in the carbide solubility. For this purpose it is, indeed, distinctly inferior to the method hereinafter described.

¹ A. Portevin, *Revue de Métallurgie*, 1908, vol. v. p. 295.

² A. Portevin and V. Bernard, "On the Practical Determination of the Critical Points of Steel by the Differential Method," *Revue de Métallurgie*, 1919, vol. xvi. p. 175.

The following are, for example, some of the results obtained, the curves having been plotted with a uniform rate of heating corresponding with the attainment of 950° in ninety minutes.

	Length in Millimetres of the Step in the Curve Corresponding with the Acl Point.	
Steel with 1.2 per cent. carbon (initially coalesced)	{ 1st curve .	21.5
	{ 2nd „ .	22.5
Steel with 0.98 per cent. carbon (initially coalesced)	{ 1st curve .	22.5
	{ 2nd „ .	25.5
Case-hardened iron with 0.70 per cent. carbon	{ 1st curve .	18.5
	{ 2nd „ .	23.5
	{ 3rd „ .	23.5
Case-hardened iron with 1.45 per cent. carbon	{ 1st curve .	21.0
	{ 2nd „ .	25.0
	{ 3rd „ .	25.0

(b) *Dilatometric Method.*—The differential dilatometrical method with the Chevenard apparatus readily lends itself, as has been seen,¹ to the investigation of the solution of cementite during heating and its precipitation on cooling. The complete solution of the latter is revealed by the reversibility of the dilatation in the γ state, a dilatation which, as regards this state, is practically independent of the carbon percentage as long as the solid solution is homogeneous. The retardation of the solubility of the cementite above Acl on heating, and its premature precipitation below Acl on cooling, are manifested by a period of intense dilatability.

If, under identical conditions of heating and of cooling, the dilatation diagrams be plotted for one and the same eutectoid steel in the globular state and in the lamellar state, it will be found that the premature precipitation of the cementite on cooling reveals itself in the coalesced steel (Fig. 3), whereas it does not appear in the steel in which the lamellar state has been regenerated (Fig. 4). It is only necessary to compare the two branches, in these figures, of the cooling curves corresponding with the γ state (above the Ar1 point).

It is equally possible, by operating on the same test-piece of a steel initially coalesced, to trace, under identical conditions of heating, three successive diagrams of dilatation by increasing, each time, the average rate of cooling, so as approximately to

¹ A. Portevin and P. Chevenard, *Comptes Rendus*, 1921, vol. clxxii. p. 1490; *Revue de Métallurgie*, July 1921.

realise the lamellar state after the first dilatation, and the troostitic state after the second. It has been in this way, for example,

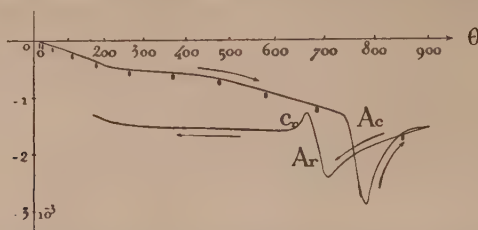


FIG. 3.—Differential Dilatometer Curves of an Eutectic Coalesced Steel. On cooling premature precipitation of cementite takes place (above A_r there is a region of high dilatation). Interval of tests, five minutes.

that the authors have obtained the following results on two steels in the neighbourhood of the eutectic:

	Variations in Length Corresponding with the A_{cl} Transformation. 10^{-3} Mm.	
In the coalesced state	0.5	0.8
After cooling in the furnace (total period, $3\frac{1}{2}$ hours)	0.9	1.2
After air cooling (total period, 20 minutes)	1.5	1.5

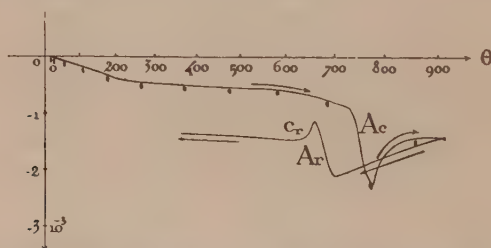


FIG. 4.—Dilatometric Differential Curves of the same steel, annealed, and with lamellar structure. On cooling the dilatation is normal above A_r . Interval of tests, five minutes.

On the other hand, the dilatometric investigation of steels with 1 per cent. of carbon and 2 per cent. of chromium, previously softened by coalescence, yields no results of interest.

(c) *Investigation of the Variation in the Properties as the Result of Successive Hardenings of the same Steel in the Globular and in the Lamellar States respectively.*—In this investigation the authors employed the same 0.98 carbon tool steel brought to the two states, globular and lamellar, by the treatments previously described, so as to obtain the structures represented in the two micrographs, Nos. 8 and 9 (Plates XV., XVI.).

Starting from these two initial states cylindrical test-pieces 8 millimetres in diameter and 150 millimetres in length were prepared, to serve for the electrical and magnetic tests, as well as other test-pieces of the same diameters and 130 millimetres long, to serve for the micrographic investigations and for the hardness tests. With this object there were made, on the latter test-pieces and previous to each quenching, a circular saw-cut, so that, by fracture, after hardening, a small cylinder could be removed.¹ The fracture surface of this cylinder after polishing and etching was examined microscopically and subsequently served to receive the ball impression (5 millimetres in diameter under a load of 500 kilogrammes).

The successive quenchings, four in number, were all carried out in water at 20° to 24°, after heating in a lead bath at 800° (to avoid any decarburisation). The periods of heating and the exact conditions of each operation are recorded in Table I., which gives the whole of the numerical data plotted in Fig. 5.

Micrography.—Etchings were in the first place made with picric acid and then, after slight repolishing, with boiling sodium picrate for eight minutes.² As a starting-point for considering the results, the cementite visible after the picrate attack, and under a magnification of 200 diameters, has been taken.

In order not to overload this paper with photomicrographs, the results of these examinations will be briefly described.

If we commence with a steel having, initially, a globular structure, we observe the gradual disappearance of the cementite in the course of the successive quenchings, but this cementite still remains visible, although in minute quantities, even after the fourth quenching.

On the other hand, with a steel having, initially, a lamellar structure, there is still plainly visible, after the first quenching, a very fine network of cementite, but this cementite disappears completely after the second quenching, and naturally does not appear again. Micrographically, then, there is a well-marked

¹ To effect this operation the test-piece was softened by tempering for two minutes in a bath of lead at 650°. If all the cuts had been made before the series of treatments the bars, thus notched, might have cracked on quenching.

² As Whiteley points out, it is preferable to precede the picrate attack by a picric acid attack which separates the cementite from the ferrite, which might possibly be spread over it by the subsequent polishing action.

difference in the behaviour, according as the initial state differs. There may further be noted simultaneously with the persistence of the globular cementite, after the first quenching, the presence of troostite, the coalescence increasing as the critical rate of

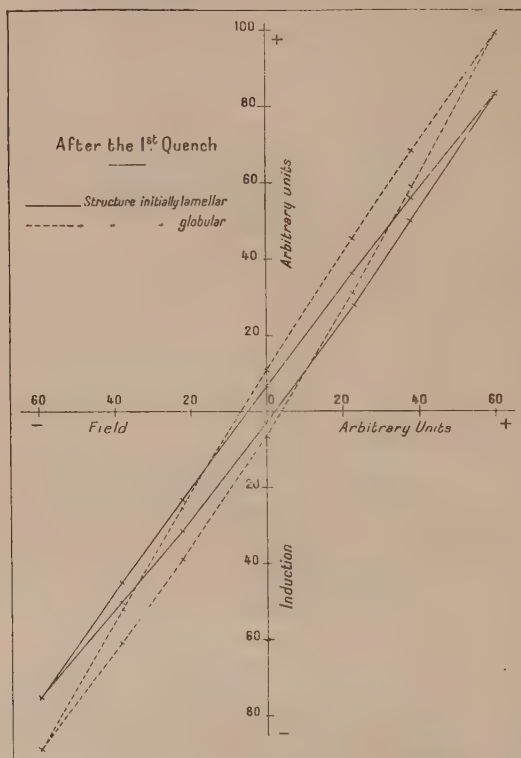


FIG. 5.

hardening increases, as already recorded by one of the present authors.¹

Electrical Resistance.—As is known, the dissolution of cementite as the result of quenching increases the electrical resistance of steel. This property has been made use of by one of the authors² to investigate the influence of the duration of heating,

¹ A. Portevin and M. Garvin, *Journal of the Iron and Steel Institute*, 1919, No. I. p. 559.

² A. Portevin, *Bulletin de la Société d'Encouragement*, 1914, vol. cxxi. p. 207.

previous to quenching, and the rate of transformation of steels on heating. An examination of the numerical data of Table I. and of the graphs relating to the resistivity in Fig. 6 shows that, despite the anomaly shown after the second quenching by the

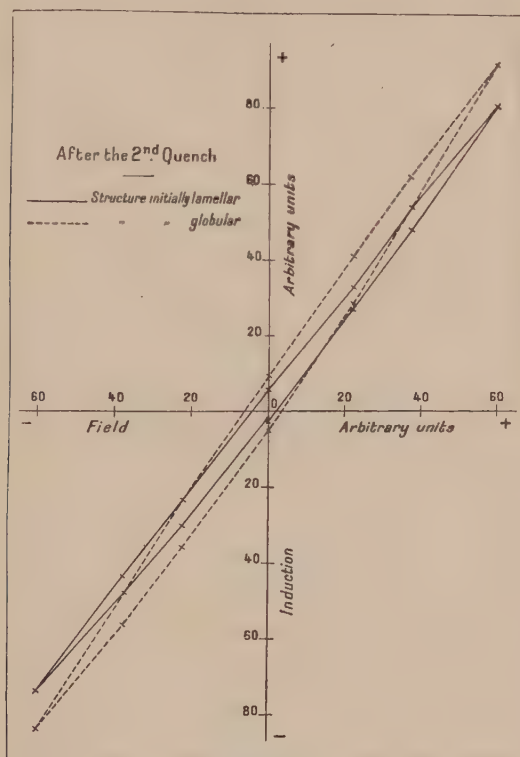


FIG. 6.

steel with, initially, a lamellar structure, the resistivities increase under the influence of the successive quenchings and tend towards a common limit. Besides this the continual growth in the resistivity of the steel with, initially, a globular structure, is more progressive, which shows the slower rate of solubility of the cementite.

Magnetic Tests.—The results of the measurements given in Table I. are shown graphically in the curves of Figs. 5 to 8.

Seeing that it is only a question of comparisons effected under identical experimental conditions these results are simply expressed in arbitrary units giving the gross results afforded by

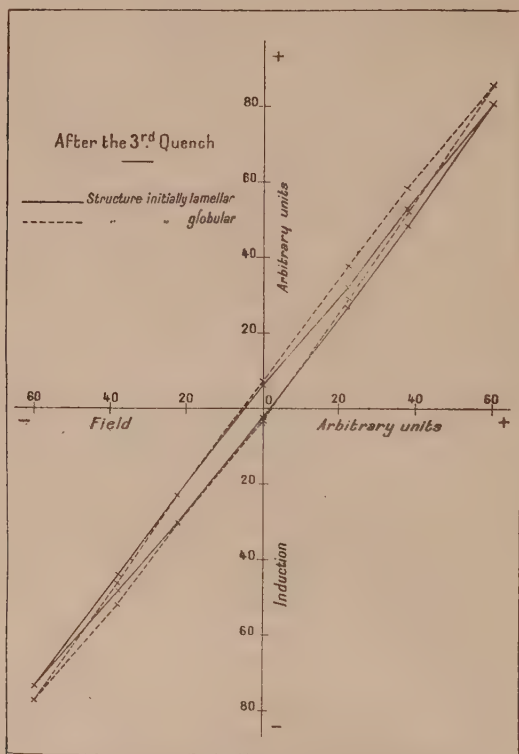


FIG. 7.

the apparatus: the intensities of current in the inductive field and the deviations of the magnetometer.

It will be seen that the hysteresis curves of the bars with initial lamellar and globular structures and not superposable after the second quenching (forty-five seconds' heating) tend toward the same appearance after the succeeding quenchings. After the fourth quench (the aggregate periods of heating having amounted to 8 minutes 30 seconds) the divergences

appeared so small that it was judged useless to continue the experiments.

In order that these observations may yield their fullest signification they should be compared with the results of the magnetic

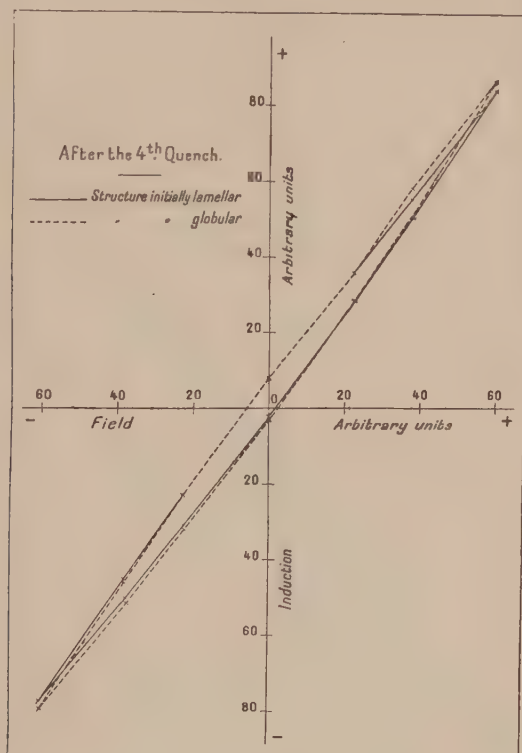


FIG. 8.

measurements which the authors carried out on bars of a hyper-eutectic steel (carbon about 1.2 per cent.), quenched at increasing temperatures. These measurements, construed in the light of the hysteresis curves in Fig. 9, show that the inductions and the remanences decrease in proportion as the temperature of quenching increases, that is to say, in proportion as the quantity of cementite dissolved before quenching increases (Fig. 10).

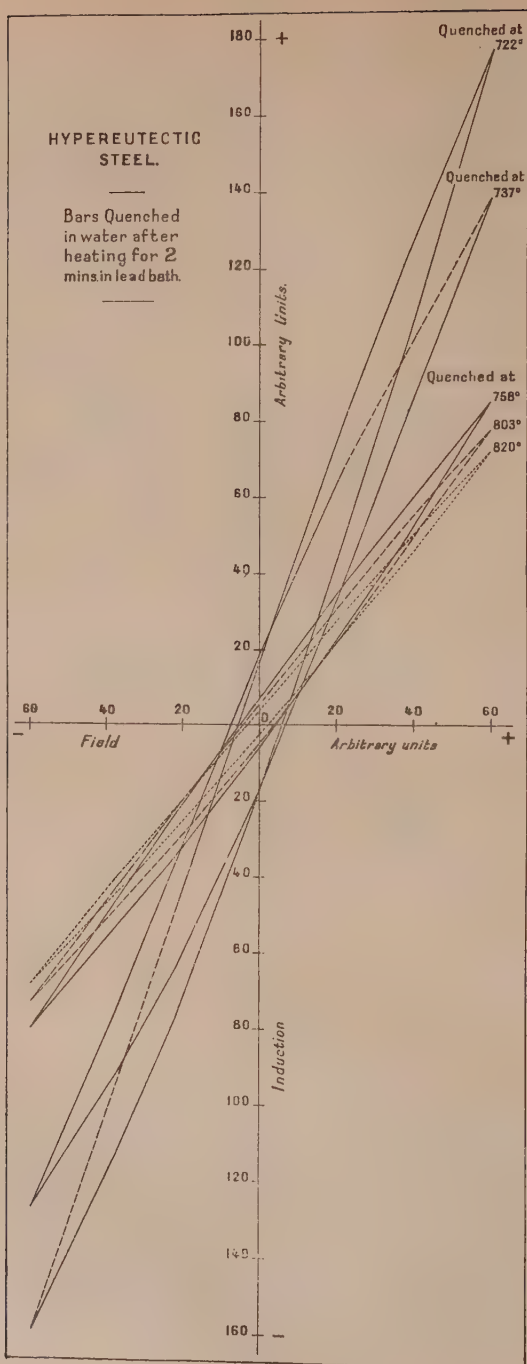


FIG. 9.

From the foregoing it will be seen that :

1. A bar with a lamellar structure should give lower induction and remanence than a bar with a globular structure when both

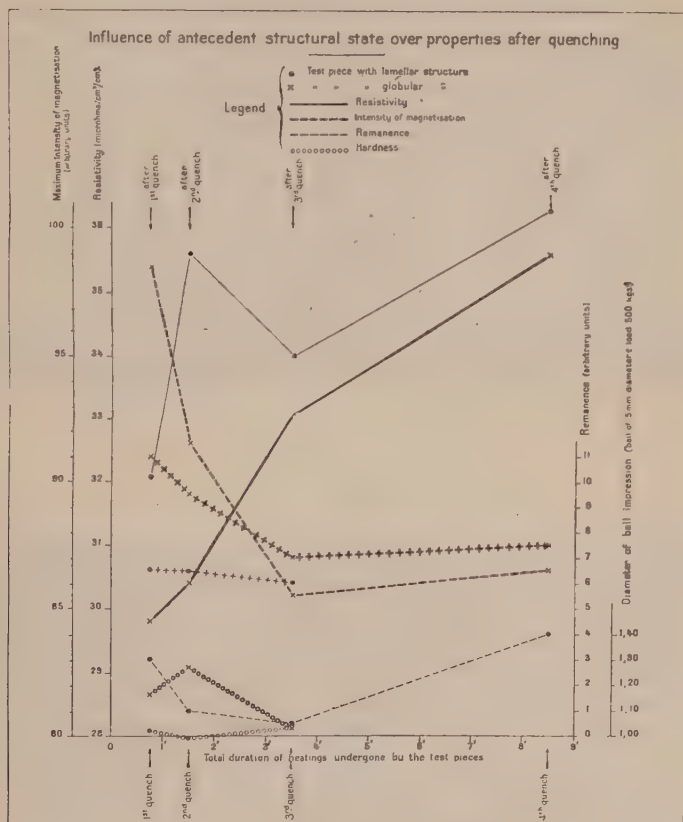


FIG. 10.

are examined in the hardened state, starting from the same temperature and undergoing the same periods of heating.

2. For the requisite period of heating before quenching the divergences between the magnetic characteristics of the two bars should counterbalance each other. That this is so is clearly brought out in the results obtained.

3. The internal state of the bar with, initially, a lamellar

structure does not attain, after the first quenching, the final stage of its development: its magnetic characteristics vary, after each quenching, in the same direction as those of the bars with a structure initially globular, although to a far greater extent. After the fourth quenching they are found appreciably to increase, a fact of which an explanation is yet to be sought. The same remark applies to the change that occurs in the characteristics of the bar with an initially globular structure after the third and fourth quenchings.

Hardness Tests.—Although the Brinell method does not lend itself well to the investigation of very high degrees of hardness, such as those of quenched hypereutectic steels, the results in Table I., represented graphically in Fig. 5, show that there is an appreciable difference in the hardness after the first quenching, corresponding with the initial structure of the steel, and that this divergence disappears after the third quenching.

CONCLUSION.

These experiments afford abundant evidence of the influence of the initial structural state on the solution of the cementite during heating, on its precipitation on cooling, and therefore on the general result of the quenching.

From the latter point of view they confirm the results of the authors' previous investigations as well as those which ordinary commercial practice in regard to the hardening of tool steel has shown; in this instance the considerations detailed in the paper are of fundamental importance both from the point of view of softening treatments and of hardening treatments.¹

The hardening treatment of a steel cannot be entirely conditioned by a knowledge of its complete chemical composition, and of the object it is sought to attain. It depends equally on the initial structural state of the steel.

The employment of coalesced hypereutectic steels conduces to modify the types of heat treatment, or to necessitate increasing the quenchings. This peculiarity constitutes an inconvenience

¹ It is unnecessary to point out the reflex action of the hardening on the penetrative capacity of the steel, a most important point when tool steels are concerned, and one to which the authors will have occasion to revert.

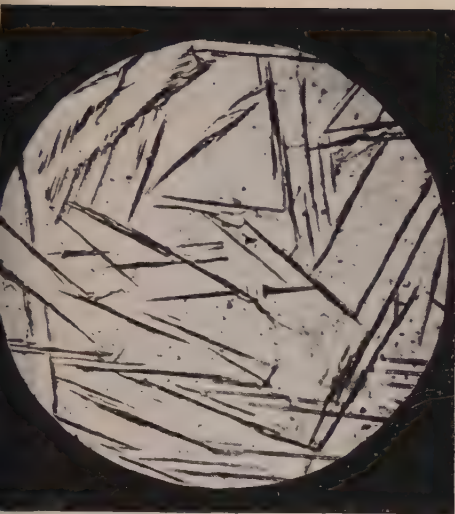


FIG. 1.
Etched with sodium picrate. $\times 200$.



FIG. 2.
Etched with sodium picrate. $\times 200$.

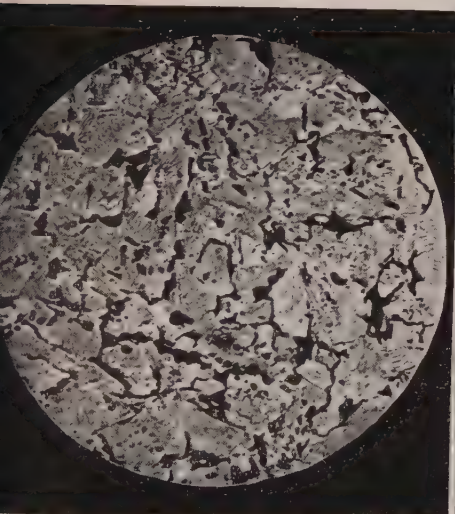


FIG. 3.
Etched with sodium picrate. $\times 200$.

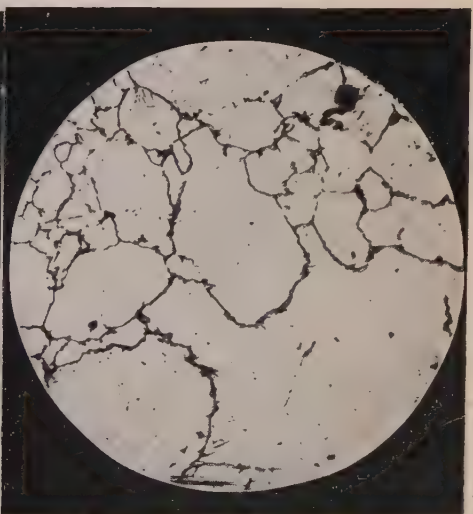


FIG. 4.
Etched with sodium picrate. $\times 200$.

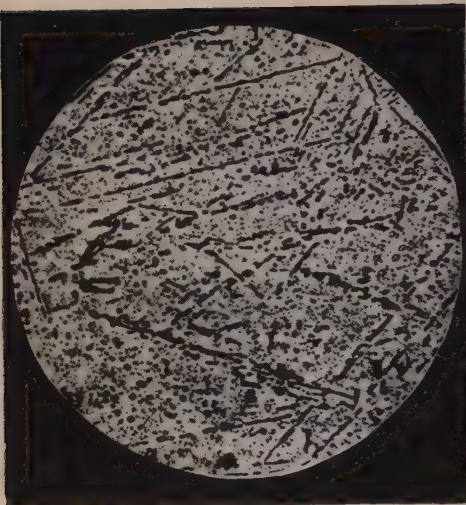


FIG. 5.
Etched with sodium picrate. $\times 200$.



FIG. 6.
Etched with sodium picrate. $\times 600$.



FIG. 7.
Etched with sodium picrate. $\times 870$.

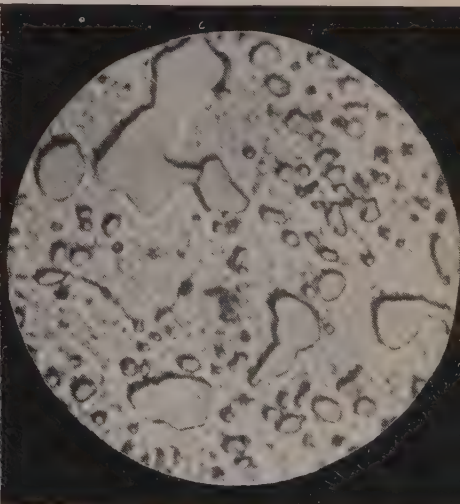


FIG. 8.
Etched with Benedick's reagent. $\times 1200$.

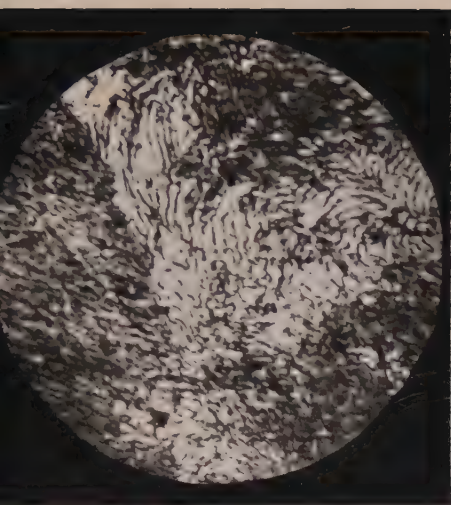


FIG. 9.
Etched with Benedick's reagent. $\times 1200$.



FIG. 12.
Etched with Benedick's reagent. $\times 530$.



FIG. 13.
Etched with Benedick's reagent. $\times 530$.

TABLE I.—*Influence of the Antecedent Structural Condition on the Properties after Quenching.*

Antecedent Structural State.	Conditions of Heat Treatment.					Diameter of the Ball Impression. (Diameter, 5 mm.; Load, 500 kgs.) Millimetres.	Resistivity in Microlm Centimetres.	Magnetism ¹ (Arbitrary Units).	
	No. of Quenchings.	Duration of Heating before Quenching.	Total Duration of the Heating Periods undergone by the Test-Pieces.	Temperature of the Lead Bath.				Maximum Intensity of the Magnetisation.	Remanence
				Original.	Final.				
Lamellar .	1st quenching	45 sec.	45 sec.	800°	798°	1.02	32.67	83.0	6.5
Globular .		45 sec.	45 sec.	803°	798°	1.16	29.77	98.5	11.0
Lamellar .	2nd	45 sec.	90 sec.	800°	804°	0.99	35.69	81.0	6.5
Globular .		45 sec.	90 sec.	807°	802°	1.27	30.40	91.5	9.5
Lamellar .	3rd	2 min.	3 min. 30 sec.	800°	800°	1.03	33.96	80.5	6.0
Globular .		2 min.	3 min. 30 sec.	803°	800°	1.03	33.06	85.5	7.6
Lamellar .	4th	5 min.	8 min. 30 sec.	803°	806°	1.03 ²	36.27	84.0	7.0
Globular .		5 min.	8 min. 30 sec.	806°	800°	1.03 ²	35.60	86.5	7.5

¹ Initial magnetic features of the test-pieces:
Lamellar structure—
Maximum intensity of magnetisation . . . 187.0
Remanence 28.0
Granular structure—
Maximum intensity of magnetisation . . . 218.5
Remanence 13.0
² Samples which cracked on quenching. Hardness measurements impossible.

for manufacturers of tools which is not always taken into account, but which should be considered side by side with the incontestable advantage afforded by using highly carburised and highly softened steels for machining (carbon over 1 per cent. and hardness lower than Brinell 180).

The difficulty of defining the state of coalescence of a given steel has rendered it, in the authors' opinion, useless for the moment to undertake detailed investigations as a whole. It is possible by a suitable regenerative treatment to restore a uniform structural state to steels so that the heat treatment need no longer be a function of the chemical composition. Hence arises the advantage of preliminary heat treatments with the object of putting the steel into the most favourable state to ensure maximum success for the results of the ultimate heat treatment.

These preliminary heat treatments may be carried out with totally different objects and notably :

1. In the present instance of hypereutectic steels, with the object of destroying the coalescence of the cementite so as to obtain, in the ensuing heating, an easier solution of the cementite and the very rapid homogeneisation of the carbon in the solid solution.

2. In the case of soft and some hard steels as cast (or superheated) to secure a preliminary chemical homogeneisation of the different elements in solution, as has been shown by the important investigations carried out by Giolitti.¹

3. In the case of soft superheated steels in order to refine the grain, as, for example, in the regenerative treatment before quenching of case-hardened parts.

Such varying objects can only with difficulty be attained by a generalised heat treatment of the kind known as normalisation; the methods should be varied in accordance with the results sought.

To sum up, there are in principle, and having regard to the most ordinary instances, only two solutions of the problem of heat treatment of a steel of given chemical composition :

1. To take into account in laying down the conditions of

¹ F. Giolitti, "The Preliminary Heat Treatment of Soft and Some Hard Steels for Machine Construction." Paris, Dunod, 1920.

the final heat treatment the existing structural state of the steel, and

2. To adopt a uniform final heat treatment based on the chemical composition of the steel by "preparing" the latter, that is to say, by previously inducing in it a structural condition, which shall always be constant, by means of a preliminary heat treatment adapted to the antecedent heat treatment history of the steel.

In regard to the latter solution, which is the best, the final heat treatment must be entirely defined—according to the object of the nature of the parts to be treated—by the characteristic curves of the steels.¹

With identical values for the magnetic field, the inductions and remanences are always higher in the case of steels with an initial globular structure than in the case of those with an initial lamellar structure.

¹ See the paper on this subject presented by A. Portevin and P. Chevenard, pp. 117-140, *ante*.

Iron and Steel Institute.

DAMASCENE STEEL.

BY COLONEL N. T. BELAIEW, C.B.

PART II.

1. IN the first paper on damascene steel,¹ presented by the author to the Institute in 1918, he described the general properties and structure of damascene steel, and pointed out the great claims it had to the attention of all interested in tool steel. The object of the present paper is to substantiate that statement, more especially as regards high-speed steels. In the author's opinion a marked analogy exists in the structure and in some of the properties of high-speed and damascene steels, and a comparative study of both might therefore prove beneficial in explaining certain properties and in opening new vistas.

2. Damascene steel belongs to the hypereutectoid series of carbon steels. As mentioned in the author's previous paper, the average carbon content of typical damascene articles must be about 1.5 per cent. That amount of carbon, however, does not exist as such but as a definite chemical compound, Fe_3C or cementite. Introducing the respective atomic weights of iron and carbon :

$$(3 \times 56) \text{ iron} + 12 \text{ carbon} = 180 \text{ Fe}_3\text{C},$$

we arrive at the result, that one part of carbon produces $\frac{180}{12}$ or fifteen parts of cementite. 1.5 per cent. of carbon in steel represents therefore 22.5 per cent. of cementite, which, from the practical point of view, is a very large amount. About one-half of this amount (11.5 per cent.) forms the excess, or free cementite. The other 11 per cent. of cementite with a corresponding amount of ferrite is used up in building up pearlite.

The free cementite is coarser than the eutectoid cementite, its spheroidisation is correspondingly more difficult and necessitates repeated hammering and heating. The greatest care must be

¹ Colonel Belaiew, "Damascene Steel," *Journal of the Iron and Steel Institute*, 1918, No. I. p. 417.

taken to break the large cementite needles into smaller particles and afterwards to cause their complete spheroidisation.

The Indian damascene blades, examined in Petrograd by the author, showed a perfect balling up, as may be seen from Figs. 3 and 4 (Plates XLII. and XLIII.) of his previous paper. The completeness of the spheroidising process may now be further illustrated by Fig. 1, which shows at a magnification of 1000 a section of an Indian blade, photographed in the author's London laboratory by Captain B. Brandt. The larger particles shown in the section are those of "free" cementite, the smaller ones are eutectoid cementites. Both groups are thoroughly spheroidised. Fig. 2 (Plate XVIII.) shows the structure revealed under higher powers ($\times 2000$).

Figs. 1 and 2 (Plates XLI. and XLII.) of the author's first paper also show what a large amount of mechanical treatment (as shown by the macrostructure of the blade) was required to attain such complete spheroidisation. The macrostructure shows also that the cementite veins run closer up to the edge, and that therefore the oriental maker must have relied most upon securing the best cutting properties of the cementite particles.

3. High-speed steel is a tool steel which possesses the property of maintaining its hardness at a relatively high temperature. This property is secured in a large degree by adding tungsten and chromium, usually 16 to 20 per cent. of the former and from 3 to 5 per cent. of the latter; the carbon content is generally not over 0.75 per cent.; up to 1 per cent. of vanadium is also added.

This steel belongs to the cementitic (carbide) series; its structure, when annealed, presents a striking similarity to the structure of damascene steel (see, for instance, Fig. 336, p. 356, of Sauveur's "Metallography"). Spheroidised carbide particles are embedded into a sorbitic matrix. To produce "high-speed hardness" such steel has to be heated to a very high temperature, and then quickly cooled. A certain amount of carbide remains undissolved, even after rapid cooling from temperatures close to the melting point (see, for instance, Figs. 334 and 342 (Yatsevitch) of Sauveur's "Metallography"). There are even indications that a moderate amount of free carbide appears to increase the cutting properties of the tool.

The actual makers of high-speed steel, however, emphasise

that the making of the high-speed structure begins under the hammer; that during this operation "the massive carbides and tungstides present in the ingot are broken down and uniformly distributed throughout the billet";¹ and further, that "to accomplish this the reduction in area must be sufficient." Therefore, ingots are first hammered into billets, the billets are again slowly heated and then hammered for a second time ("cogged")—all this "mechanical treatment" being indispensable in paving the way to the "heat treatment" by properly breaking and evenly distributing the carbides (and tungstides) throughout the steel.

4. If we proceed now to compare not only the photomicrographs, but also the two processes—the "high-speed hardness" and the "damascene" process, we see how similar they are.

Both start with a cementitic steel; both require the greatest care in breaking and evenly distributing the carbides under the hammer; in both cases the amount of mechanical work spent on a given article is very large, but however large it is considered indispensable before a suitable heat treatment may be effected. In both cases the structure of carbides is spherulitic, whilst the matrix, after the heat treatment, is martensitic. In both cases also the cutting properties of the edge are related not only to the matrix, but to the carbides as well. The author is even inclined to think that the properties and the distribution of the carbides play a more considerable rôle than the matrix. On this ground may be explained the reason why, on the one hand, such diversities of opinion exist as to the structure of the matrix in high-speed steels, whilst, on the other, neither the old Eastern makers nor Anossov seemed to attach any real importance to the tempering of damascene steel. The author's studies in this field have led him to the belief that whilst being very strict as regards the hammering temperatures, nobody who has really busied himself with damascene steel cared much as to its subsequent heat treatments.

5. There are a few conclusions which can be drawn from these preliminary remarks:

First, there is the question of spheroidisation of the carbides.

¹ "The Manufacture of High-Speed Steel in the Electric Furnace," by Rog. C. McKenna, President of the Vanadium-Alloy Steel Corporation. *Transactions of the American Electrochemical Society*, vol. xxxvii. p. 322.

In damascene steel the degree of spheroidisation is always very high. That spheroidisation, however, was not an end in itself for the ancient maker, but was attained, so to say, incidentally during the numerous cautious forgings and heatings, when the greatest ductility was sought and obtained.

In high-speed steels that spheroidisation is also attained, but it seems to the author that insufficient stress has been laid on that point, either by the high-speed steel maker, or user. He believes that a scientific application of the spheroidising process would help to improve the qualities of high-speed steel. He thinks, further, that another inference from the damascene process might be drawn, namely, the proper study of the macrostructure. An oriental maker would never manufacture a steel article without having satisfied himself, by studying the watering, that the distribution of the carbides is the best possible and quite in accordance with the shape and properties of the article. Neither would he find a buyer ready to accept a sword or a tool without a proper "metallographic" examination of it as a whole (towards that end the splendid oriental watering lent itself so well). The author therefore believes that a proper examination of the "watering" of high-speed steel, either in billets or in the finished article, will prove useful.

As to the damascene steels, whilst not ready to place them in the category of high-speed steels, the author is, however, inclined to think that a certain "high-speed hardness" which he noticed during his experiments on damascene steel (interrupted by the war) might prove not quite accidental, but useful for further investigation.

The author takes this opportunity to express his sincere thanks to Captain B. Brandt for the kind assistance he has given in preparing slides for microscopic examination and in taking photomicrographs. He hopes to place before the members of the Iron and Steel Institute a further contribution on the subject of Damascene Steel (Part III.), based on an examination, now being carried out, with Captain Brandt and Mr. Camp's assistance on specimens in the Wallace Collection, to the Curators of which he also desires to express his indebtedness.



FIG. 1.

An Indian Blade from the Author's collection. Globules of spheroidised
cementite embedded in a sorbitic matrix

× 1000.

τ

[To face p. 184.



FIG. 2. $\times 4000$ and reproduced $\frac{1}{16}$ original size.

Iron and Steel Institute.

DOES THE CRITICAL POINT DEPEND ON
THE STRENGTH OF THE MAGNETISING
FIELD ?

By KÔTARÔ HONDA (TOHOKU UNIVERSITY, SENDAI, JAPAN).

It is generally accepted that the critical point or A2 transformation point is not affected by the strength of the magnetising field. By the critical or A2 point is meant a temperature at which ferro-magnetism vanishes, or at which the substance changes from the ferro-magnetic to the para-magnetic, but not the point at which the change of magnetisation, or the evolution or absorption of heat, is a maximum, as usually taken by metallurgists. Numerous experiments previously made for the determination of the critical point were mostly made with the magnetometer, and hence its determination was not sufficiently accurate. The strength of field was usually varied up to several hundred C.G.S. units, and within this range, and according to the accuracy attained, the critical point was practically found to be independent of the strength of field.

For an accurate determination of the critical point in different magnetising fields it is necessary to use an apparatus of higher sensibility, such as a torsion-balance as constantly used in our laboratory. We measured the magnetisation of iron and steels in the vicinity of their critical points by varying the magnetising field from 400 to 2150. Since in the vicinity of the critical point the ferro-magnetic intensity is extremely small, it is almost independent of the form of the specimen, and the applied field is nearly the same as the internal effective field. The specimens used had the following constituents :

Specimens.	Carbon per Cent.	Man- ganese per Cent.	Silicon per Cent.	Sulphur per Cent.	Phos- phorus. per Cent.	Copper per Cent.
Iron P. 86	0.0085	trace	0.005	0.005	trace	0.001
Steel 1	0.68	0.51	0.19	0.037	0.019	...
„ 2	1.17	0.48	0.31	0.011	0.012	0.101

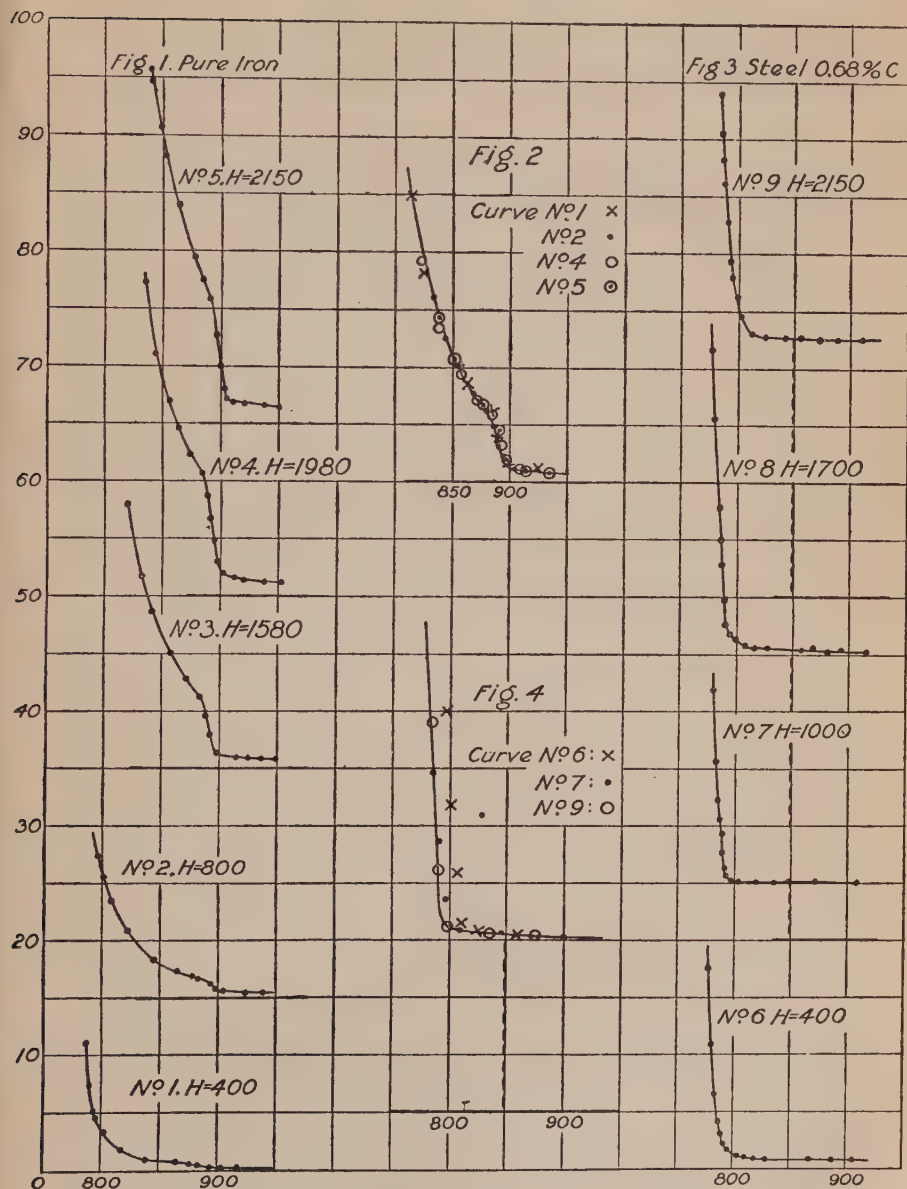
The details of the torsion-balance used in our experiments were given in Dr. T. Ishiwara's paper.¹ The measurement of the magnetisation at high temperatures was made in a vacuum in order to avoid oxidation of the specimens. For each specimen four different fields were employed ; but in order that the effect of decarburisation in steels should not complicate the phenomenon in question, the specimens were renewed in every heating and cooling, that is, for each magnetising field. The temperature was measured by a platinum-platinum-rhodium thermocouple.

The results of experiments for pure iron are given in Fig. 1, curves Nos. 1 to 5 ; the ordinate represents the deflection of the torsion-balance in degrees, which is proportional to the intensity of magnetisation, and the abscissa the temperature of the specimens. The first four figures are the deflection-temperature curves in the vicinity of the critical point, for magnetising fields of 400, 800, 1580, 1980, 2150 C.G.S. units. Here, as the critical point, we take the temperature, where the curves bend most rapidly ; because, strictly speaking, these curves are quite continuous, and there is no definite point to be distinguished from others. Above the critical point we observe an abrupt fall of the curve, which is characteristic of iron and due to the A3 transformation.

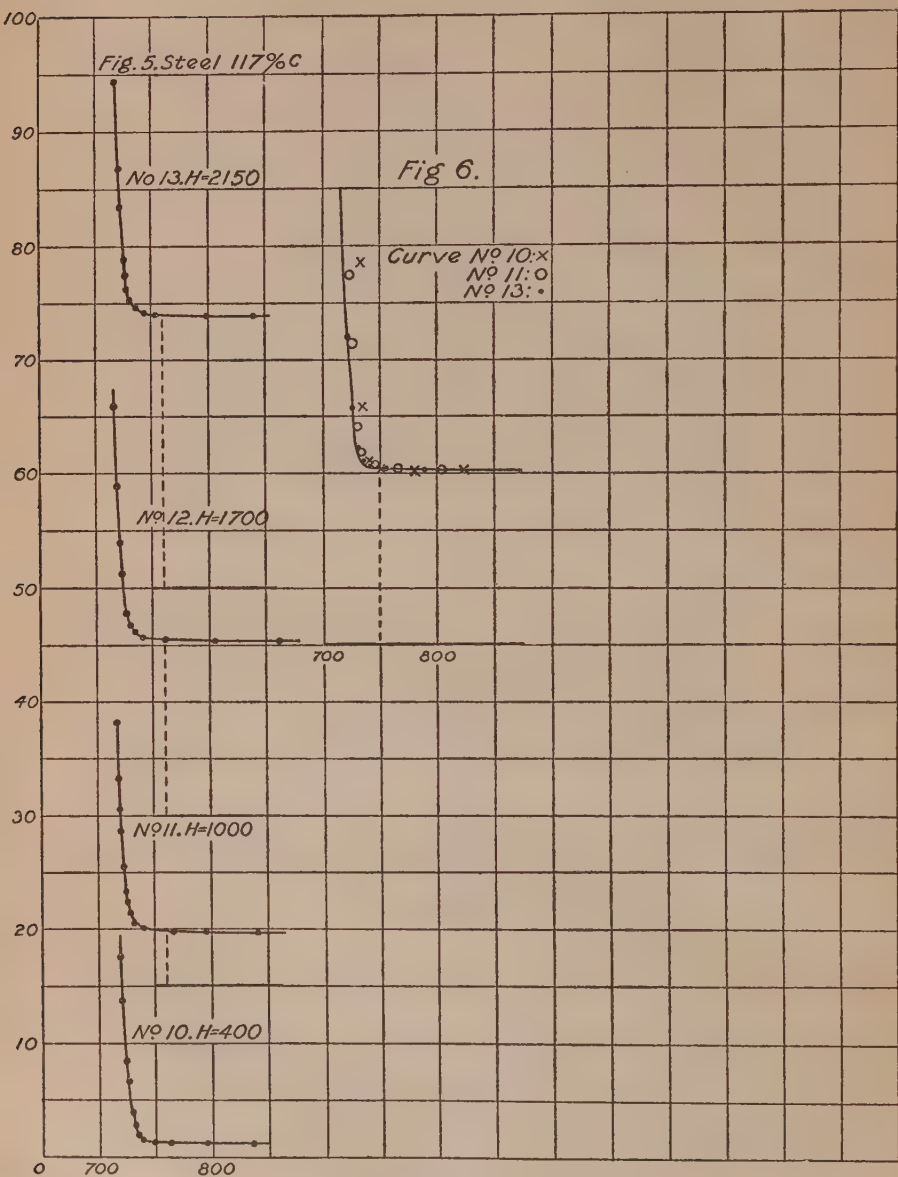
In the range of the critical point the intensity of magnetisation is proportional to the magnetising field, and hence the height of the curves increases with the latter. These curves appear therefore at first sight to indicate that the critical point rises with the increase of the magnetising field. But if we reduce these curves to those of susceptibility-temperature by dividing the ordinate by mH , $\frac{\delta H}{\delta y}$, where m is the mass of the specimen,

H and $\frac{\delta H}{\delta y}$ the strength of the field and its gradient respectively, the new curves will be very convenient for comparing the critical points corresponding to different magnetising fields with each other. Since above the critical point the magnetisation is proportional to the magnetising field, the same object will also be attained by simply reducing the ordinates of these curves by amounts such that all these curves pass through a point on

¹ *Sci. Rep.*, 1920, vol. ix. p. 233.



FIGS. 1, 2, 3, and 4.



FIGS. 5 and 6.

curve No. 3, say 850° . In Fig. 2 the points on these curves are given; from the distribution of these points we may conclude that the critical point is independent of the strength of the magnetising field.

The results of experiments for two steels, 0.68 per cent. C. and 1.17 per cent. C. , are given in Figs. 3 to 6; for each steel four different magnetising fields, 400, 1000, 1700, 2150, are used. Figs. 3 and 4 refer to a hypoeutectoid steel, 0.68 per cent. C. ; here the A3 point considerably falls as compared to that of pure iron, and almost coincides with the critical point. Fig. 4 contains the points on curves Nos. 6 to 9 in Fig. 3; we notice that the critical point is independent of the magnetising fields. Figs. 5 and 6 refer to a hypereutectoid steel, 1.17 per cent. C. ; we also observe that the critical point remains unchanged for different magnetising fields. In this case, we also notice that in weak fields the growth of magnetisation just below the critical point becomes less steep as the field increases. This phenomenon is explained in the following way:

It is well known that in weak fields the magnetisation remains almost constant near the critical point, and then diminishes to almost zero very rapidly; but that as the field is increased the magnetisation begins to decrease from a lower temperature. These phenomena are explained as the result of two opposite effects of thermal agitation¹ on the molecular magnets in the substance. The first effect, which is to increase magnetisation, is conspicuous only in weak fields; but the second, which is to decrease magnetisation, exists in all fields. In the above experiments the specimen is very short, and therefore, in the ferromagnetic region, the demagnetising factor is very large. Hence in weak fields, when the magnetisation increases very rapidly below the critical point, the demagnetising force also increases rapidly, and hence the effective internal field becomes small. It follows, therefore, that owing to the first effect of thermal agitation, the increase of susceptibility below the critical point becomes greater as the field is weaker.

It is here not out of place to remark that in the magnetic analysis for studying the structure of a ferro-magnetic steel, it is necessary to use a specimen having a dimension-ratio (length :

¹ *Sci. Rep.*, 1916, vol. v. p 325.

diameter) greater than about 15 and to apply a magnetising field of about 200 C.G.S. units. If we use a short specimen, for example, 1 centimetre thick and 3 centimetres long, the demagnetising factor is very large ; and hence, though an external field of a few hundred units is used, the effective field will be less than 10 units. In this case, the relation of magnetisation to temperature will be complicated by the first effect of thermal agitation, and therefore small changes of magnetisation due to those of structure cannot be detected. Hence for studying the structure of a steel by magnetic analysis it is not advisable to use a short specimen.

Summing up the above results, we arrive at the conclusion that the critical point is not affected by the magnetising field. The magnetic or A2 transformation is very probably a progressive change going on in the molecules themselves with the rise of temperature, and the change of magnetisation is only one aspect of this internal transformation as revealed magnetically. The critical point of such an internal change will not easily be affected by an external factor, such as a magnetic field.

In conclusion, I wish to express my hearty thanks to Mr. Y. Nuka for his zealous assistance in taking observations.

Iron and Steel Institute.

AN INVESTIGATION OF HOT DRAWING ON
THE MANDRIL.¹

BY EUGÈNE SCHNEIDER (PAST-PRESIDENT).

INTRODUCTION.

THE operation of hot drawing on the mandril is relatively simple, yet the actual conditions under which the work is carried out are but little known.

To study the elements of drawing the practical man bases his knowledge on preceding work which has given good results, and in this way surprises often occur in the tests. Moreover, the conditions of efficiency are bad.

The very large variety of blanks of all dimensions that we have been called upon to manufacture permits us to make numerous observations. The study that we have drawn up is made especially for the needs of the shop; the theoretical part has been reduced as much as possible, and the conclusions should permit of a very rapid and certain determination at sight on all the elements of a drawing.

The trial tests can be done without fear of any incidents, and the operation giving the best efficiency for a specific product with hydraulic machines of specified duty can be obtained.

Under these conditions the method of working will no longer be empirical.

PART I.

GENERALITIES.

I. *Object of Drawing.*

The drawing on the mandril has for its object the lengthening of a hollowed blank obtained by punching or casting and keeping it, by means of a mandril, to the required internal section and dimensions.

¹ This paper is in continuation of the researches published under the title "An Investigation of Various Forging Operations carried out under Hydraulic Presses," *Journal of the Iron and Steel Institute*, 1920, No. II. p. 223, and the translation has been kindly supplied by the author.

II. Description of Drawing.

The operation of drawing is carried out with the aid of different machines: hydraulic drawing presses, draw benches, and mechanical or electrical draw presses.

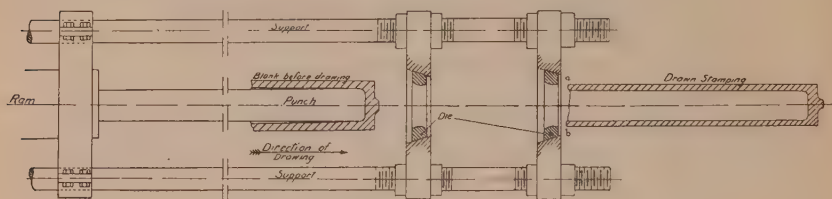


FIG. 1.

Generally, and especially in the cases that we have studied, the hydraulic press is the machine used.

The mandril or punch is fixed to the cross-head of the press, as indicated in Fig. 1.

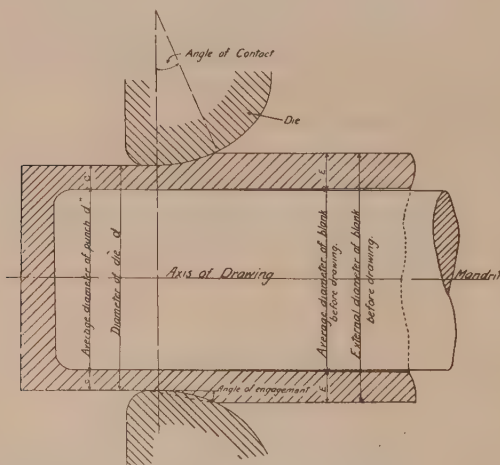


FIG. 2.

On this mandril the blank to be pressed is introduced.

By its forward movement the punch entrains the rough blank and makes it pass through one or several dies placed on the same centre line as the punch, their internal diameters being such

that they can occasion the required elongation of the blank as it passes each one.

The blank thus pressed perfectly fits the profile of the punch.

To disengage it, at the end of the stroke between the free section *ab* of the blank and the die-plate carrier, an extractor which caps the punch is interposed, which on the return stroke of the press rests against the section *ab*, and causes disengagement.

III. Definitions and Notations.

Fig. 2 represents a blank in the course of drawing. For the study which follows we will adopt the following notation and definitions :

D.—Average external diameter of blank before drawing.

d' .—Average internal diameter of blank before drawing.

E.— $\frac{D - d'}{2}$. Average thickness of blank before drawing.

d .—Diameter of die or diameter of blank after drawing.

d'' .—Average diameter of punch.

e.— $\frac{d - d''}{2}$. Average thickness of sides of blank after drawing.

θ .—Angle of Contact. This angle is determined by the two connecting radii of the die, which indicate the limits of the zone of the blank in contact with the die during drawing.

$\frac{\theta}{2}$.—Angle of Attack. This angle is that made by the chord of the arc of contact with the press axis.

S.—Remaining Section = $\frac{\pi}{4} (d^2 - d''^2)$. This section is that of the blank after its passage in the die.

s.—Displaced Section = $\frac{\pi}{4} [(D^2 - d'^2) - (d^2 - d''^2)]$. This section is the difference of the sections of metal of blank before and after drawing.

Elongation per cent. = $\frac{s}{S} \times 100$.

IV. Generalities on the Forms of Roughed Blanks and Tools Used.

(a) *Roughed Blanks*.—When referring to roughed blanks required for cylinders, tubes, &c., the interior is cylindrical before drawing, and the internal diameter is slightly greater than the diameter of the punch in order to allow the entry of the latter to the bottom of the blank.

For the manufacture of shells the interior form of the roughed blank is different ; the lower part is always conical, but the maximum internal diameter remains greater than that of the punch. We understand by internal diameter of the blank before drawing, the diameter corresponding to the greater diameter of the punch.

The external form of the blanks is variable according as to whether they have not been drawn, or submitted partially to this operation. We will distinguish therefore the two cases.

1. The blank is punched but not drawn.

The external form is the same as that of the die of punching ; it is therefore conical. We will assume that the average external diameter and the average thickness before drawing are measured at half height of the upper cone of the die.

2. The blank has already been partially drawn. The external form is cylindrical.

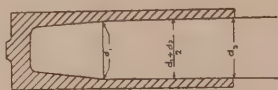


FIG. 3.

(b) *Punches*.—The mandrils or punches are all more or less conical according to the product to be obtained.

In the case of tubes or of reservoirs where the thickness of the walls must be as regular as possible, the coning of the punch is small ; in this case we will take as average diameter, the average diameter of the part covered over by the drawn blank.

For the manufacture of shells the punch generally consists of a series of cones, as indicated in sketch above (Fig. 3).

In this case we will take, as average diameter of the punch, the average diameter of the largest part covered over by the drawn blank.

(c) *Dies*.—The dies we utilise are of two types, of which the sections are indicated in Figs. 4 and 5.

The section of the die consists of a rounded portion of radius R , which connects to a cylindrical portion ab of variable length, but always rather small.

To simplify the study we assume that the rough blank adheres to the punch in the region in contact with the die.

The angle of contact θ therefore corresponds to the diminution of thickness of side Ee .

The section of the die consists of a rounded portion of radius R , connecting on one side to the cylindrical part ab and on the other to a conical part cd . In the case where the contact of the blank will be made with the conical part cd (at A , for example), we will have as arc of contact the portion Aa , and in order to be able to compare with dies with ordinary connection, we will assume that the portion Aa is equivalent to the arc of a circle whose centre is situated on the line ax , this arc passing by a and A .

The angle of contact will be that indicated in Fig. 5.



FIG. 4.—First Type.

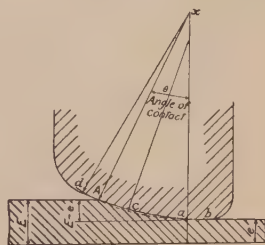


FIG. 5.—Second Type.

PART II.

EXAMINATION OF THE WORKING CONDITIONS.

I. *The Different Forces in Operation during Drawing.*

Suppose a blank in course of drawing is as represented in Fig. 6. We will assume that the diameters of the punch and of the blank are the average diameters defined above.

To simplify the study we will suppose that the internal diameter d' of the blank before drawing is the same as the average diameter of the punch.

By the intermediary of the punch the blank is submitted to a tensile force P , which acts on the section of the metal situated behind the die.

The section of the metal of the blank after its passage in the die, that we have termed the remaining section S , is equal to

$$\frac{\pi}{4} (d^2 - d''^2).$$

If ϕ is the stress per square millimetre carried by the remaining section, we have :

$$\phi \times S = P \quad . \quad . \quad . \quad (1)$$

The tensile force P is balanced by the resistance opposed on the die by the section of metal in contact with it, that is to say, by the section of metal displaced s , which is equal to $\frac{\pi}{4} (D^2 - d^2)$.

If we call R the resistance per square millimetre of the metal

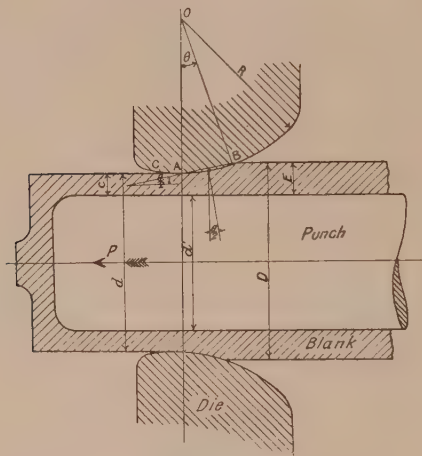


FIG. 6.

to displacement, the total resistance opposed by the section s will be $R \times s$.

We shall have therefore—

$$P = R \times s \quad . \quad . \quad . \quad (2)$$

From formulæ (1) and (2) we have—

$$\phi \times S = R \times s, \text{ from which } \frac{\phi}{R} = \frac{s}{S}.$$

The stress carried by the remaining section is equal to the resistance to displacement of the section displaced. In order that a blank can be drawn it is therefore necessary that the strain ϕ per square millimetre of remaining section be less than the breaking strain.

The formula $\frac{\phi}{R} = \frac{s}{S}$, also shows that $\frac{\phi}{R}$ is equal to the ratio

of the section displaced to the remaining section, or, in other words, to the elongation.

We will determine in what limits R and ϕ can be varied. These values once known allow us to determine all the elements for drawing.

II. *Measurement of the Power necessary at Drawing.*

In order to be able to find the different values of R and ϕ , it is absolutely necessary to know exactly the power required in drawing.

Numerous readings have been made by the aid of an apparatus registering times and pressures in relation to the stroke, as we

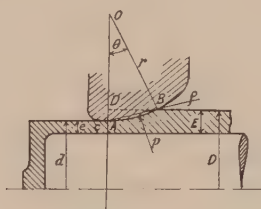


FIG. 7.

have described in a previous paper.¹ These have enabled us to plot Tables I., II., III., and IV., which will be found at the end of the present paper.

The powers that we have given in these tables are those exactly necessary at drawing—that is, they do not take into account the power absorbed by the press at no load.

The diagrams given show that the pressure increases as the pass is made, owing to the cooling of the blank. We have taken as average pressure in the course of drawing the pressure which is maintained during the great st part of the operation.

III. *Variations of the Resistance to Displacement: R.*

In practice the connecting radius of the dies is sufficiently large and in the neighbourhood of 100 mm., and for very important passes the diminution of thickness of the sides is scarcely ever

¹ *Loc. cit.*

more than 15 mm. One can, without any appreciable error, replace in the calculation the arc of contact AB by the chord AB.

In fact, let us suppose

$$OB = r = 100 \text{ mm.}$$

and

$$AD = E - e = 15 \text{ mm.}$$

We have

$$\text{Arc AB} = \frac{\pi r \theta}{180}.$$

$$\text{Chord AB} = \sqrt{BD^2 + AD^2}.$$

or

$$BD = \sqrt{(2r - AD) \times AD} = \sqrt{185 \times 15} = \sqrt{2775} = 52 \text{ mm} \quad . \quad (6)$$

$$\text{Chord AB} = \sqrt{2775 + 225} = \sqrt{3000} = 54 \text{ mm.}$$

On the other hand

$$\text{Sin. } \frac{\theta}{2} = \frac{AB}{2r} = \frac{54.7}{200} = 0.2735 \quad . \quad . \quad . \quad (7)$$

from which

$$\frac{\theta}{2} = 15^\circ 50' \text{ and } \theta = 31^\circ 40',$$

and

$$\text{Arc AB} = \frac{\pi \times 100 \times 31^\circ 40'}{180^\circ} = \frac{3.14 \times 1900}{108} = 55 \text{ mm. } 25.$$

It can be seen that in the case of a heavy pass the difference between the chord and the arc is 0.55 mm., namely, of the order of 1 per cent. We can therefore, without any great error, substitute the chord for the arc.

We have seen that if P is the force necessary for drawing, this force is balanced by the resistance to displacement of the section of metal to be displaced.

$$P = R \times s.$$

This resistance to displacement is due :

1. To the reaction of the metal on the part AB of the die.
2. To the friction (rubbing) of the zone of contact with the die.

Let p be the unit pressure on the die and l the length of the chord AB.

The surface of the cone of contact (in replacing, as we have said, the arc AB by the chord AB) is :

$$s' = \frac{\pi (D + d)}{2} \times l,$$

or

$$l = \frac{D-d}{2 \sin. \frac{\theta}{2}}$$

from which

$$s' = \frac{\pi (D^2 - d^2)}{4 \sin. \frac{\theta}{2}}$$

The total reaction on the cone of contact of the die is therefore :

$$P_1 = p \times \frac{\pi (D^2 - d^2)}{4 \sin. \frac{\theta}{2}}$$

and the projection of this reaction on the centre line is equal to :

$$P'_2 = p \times \frac{\pi (D^2 - d^2)}{4 \sin. \frac{\theta}{2}} \times \sin. \frac{\theta}{2} = p \times \frac{\pi}{4} (D^2 - d^2).$$

The friction on the cone of contact in designating f the coefficient of friction is :

$$P_f = p \times f \times \frac{\pi (D^2 - d^2)}{4 \sin. \frac{\theta}{2}}$$

and the projection of this force on the centre line is :

$$P_f = \frac{\pi (D^2 - d^2)}{4} \times \cot. \frac{\theta}{2} \times p \times f.$$

In the cylindrical part Ac of the die there is also friction, but it is only due to a pressure p' , a function of the elasticity of the metal which has been drawn. Now, in hot metal at the usual working temperatures this elasticity is practically zero, and on the other hand, the length of the cylindrical portion of the dies being generally small, we can neglect this friction in the equation of equilibrium.

(In cold-drawing this term would not be negligible, since the elasticity is higher when the pass is heavier, that is to say, when the drawn part has undergone more cold-work.)

We have therefore the equation of equilibrium :

$$P = P'_2 + p'f,$$

where

$$P = p \frac{\pi}{4} (D - d^2) + p'f \cot. \frac{\theta}{2} \times \frac{\pi}{4} (D^2 - d^2),$$

or

$$P = \frac{\pi}{4} (D^2 - d^2) p \left(1 + f \cot. \frac{\theta}{2} \right).$$

We have seen that

$$\frac{\pi}{4}(D^2 - d^2) = s = \text{section drawn away}$$

Therefore

$$P = s \times p \left(1 + f \cot \frac{\theta}{2} \right)$$

Where the resistance to displacement

$$R = p \left(1 + f \cot \frac{\theta}{2} \right) \quad (1)$$

1. *Variation of R according to Section of Die.*—We can allow that for the same temperature and dies in the same state p and f are constant. It is seen therefore from equation (1):

If we operate under the same conditions of temperature and with dies whose surfaces of contact are in the same state, the resistance to displacement increases as the angle of contact decreases.

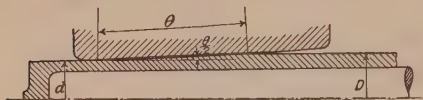


FIG. 8.

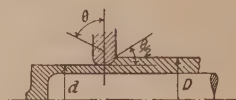


FIG. 9.

In other words, for a given pass, the greater the angle of contact, or the smaller the connecting radius, the less becomes the power necessary for drawing.

If the angle of contact θ is very small (Fig. 8) the value of $\cot \frac{\theta}{2}$ is very great, consequently the friction increases, and, due to the normal reaction, the metal tends to wedge instead of to be displaced.

If, on the contrary, assuming always the same proportionate reduction of section, the angle of contact θ is very great (Fig. 9), $\cot \frac{\theta}{2}$ decreases and the friction becomes negligible. The power necessary then becomes in the neighbourhood of the minimum. The section of the metal to be displaced works at this moment under shear, and the effort of drawing can create tears on this section.

From this it appears that it is advantageous to employ dies of small connecting radius.

However, in order to avoid the tearing of the metal which would result from a very short cone, it is necessary to find a normal section, and it is experience which has enabled us to determine this.

The angle of attack $\frac{\theta}{2}$, which seems to be the limit of the opening of the cone, is about 15° . For a larger inclination there is the risk of the tearing of the metal to be displaced.

We have allowed for $\frac{\theta}{2}$ as maximum: 15° .¹ Now $\cot. 15^\circ = 3.75$ in round figures.

Consequently for this maximum angle

$$R = p(1 + 3.75f).$$

With an angle $\frac{\theta}{2}$ inferior to 15° , R increases very rapidly.

Also for

$$\begin{array}{ll} \frac{\theta}{2} = 10^\circ & \cot. \frac{\theta}{2} = 5.6 \\ \frac{\theta}{2} = 5^\circ & \cot. \frac{\theta}{2} = 11.4 \end{array}$$

If we take, in order to compare R , $f = 0.35$, we have

$$\begin{array}{ll} \frac{\theta}{2} = 15^\circ & R = 2.31 p \\ \frac{\theta}{2} = 10^\circ & R = 2.96 p \\ \frac{\theta}{2} = 5^\circ & R = 5 p \end{array}$$

These three values of R , for constant p , show clearly the interest to adopt an angle of attack in the neighbourhood of 15° .

Fig. 7 gives us

$$\cot. \frac{\theta}{2} = \frac{BD}{AP}$$

or

$$BD = \sqrt{\left(2r - \frac{(D-d)}{2}\right) \frac{(D-d)}{2}}$$

and

$$AD = \frac{D-d}{2}$$

¹ It should be noted that this angle of attack, which corresponds to an angle of contact $\theta = 30^\circ$, puts us practically in the same conditions as for rolling where a maximum angle of contact of 28° is allowed.

from which

$$\text{Cot. } \frac{\theta}{2} = \sqrt{\frac{\left(2r - \frac{(D-d)}{2}\right) \frac{D-d}{2}}{\frac{(D-d)^2}{2}}} = \sqrt{\frac{2r - \frac{D-d}{2}}{\frac{D-d}{2}}}$$

If we make

$$\frac{\theta}{2} = 15^\circ \quad \text{cot. } \frac{\theta}{2} = 3.75$$

we have

$$3.75^2 \times \frac{D-d}{2} = 2r - \frac{D-d}{2}$$

or in round figures

$$2r = 15 \times \frac{D-d}{2}$$

from which

$$r = 7.5 \times \frac{D-d}{2}$$

Consequently—

For a diminution of thickness of sides $\frac{D-d}{2}$ the die which permits working under the best conditions is that where the connecting radius is equal to about seven and a half times the diminution of the thickness of sides.

This condition of efficiency of the die does not always occur in practice, especially where different passes must frequently be made on very different blanks.

It can be imagined the stock of dies it would be necessary to have at hand for a determined pass for a given blank, the die being of a convenient section.

The following table gives the ideal values of the connecting radius r in relation to the pass of drawing :

Reduction of Thickness of Walls $\frac{D-d}{2}$ in mm.	$r = 7.5 \frac{D-d}{2}$ in mm.
Mm.	Mm.
2	15
4	30
6	45
8	60
10	75
12	90
14	105
16	120
18	135
20	150

Value of the Coefficient of Friction.—The value of the coefficient of friction is rather difficult to determine exactly, since it is a function of the state of the surfaces of the die and of the blank, as also of the temperature of drawing.

In cold-drawing, with polished dies and with blanks without wrinkles, Codran gives $f = 0.15$. In rolling a coefficient of friction of 0.35 to 0.4 is allowed. The temperature of rolling being generally higher than that of drawing, we can allow without serious error $f = 0.35$ for all hot-drawing.

This coefficient varies with the degree of wear of the die. One can observe that in normal operation from the following fact: if we draw with a very worn die presenting large erosions and where we can replace it by a new die of a little less diameter, we find a slight reduction of pressure at the press-head, namely a reduced power absorbed due to the fact that f is reduced.

Nevertheless as our tables have been made during normal operation, with dies practically in a similar state, we allow practically as a constant value of the coefficient of friction, $F = 0.35$, in the ordinary limits of the temperatures of drawing.

If we take the best conditions of die section, that is to say, with

$$r = 7.5 \frac{D-d}{2} + f = 0.35$$

we have

$$R = p \left(1 + f \cot. \frac{\theta}{2} \right).$$

where

$$\left(1 + f \cot. \frac{\theta}{2} \right) = 2.31$$

$$R = 2.31 p.$$

2. *Variations of p .*—The temperatures of drawing ordinarily vary, according to the types of blanks, from about 800° to 1050° .

After the information we have been able to collect the tensile strength curve in function of temperatures of semi-hard steel would have approximately the form that we have traced in Fig 10.

The greater the temperature of a blank, the less high will be the power necessary, consequently p will be as much less as the temperature will be increased. As in drawing we act in some form of tension on the section to be displaced, the curves of the value of p in relation to the temperature will be practically analogous to that of Fig. 10.

It would be sufficient to determine exactly the curve of the values of p in relation to the temperature in order that at each instant we could deduce the value of R and the corresponding power.

In order not to remain in a purely theoretical domain, we will instance some well-defined cases.

We have treated more especially the case of large blanks, besides, they are the more interesting, as much on account of the

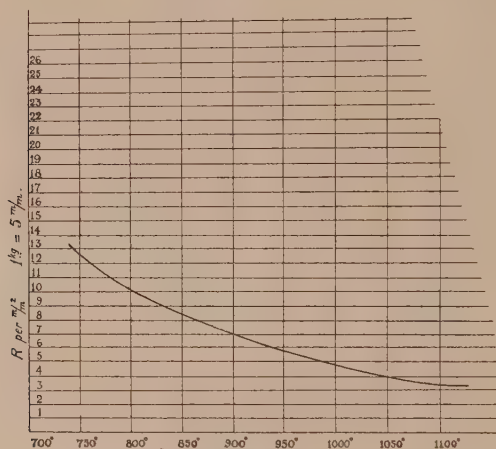


FIG. 10.

varieties of the examples as for the importance of the works carried out.

For the drawing of these blanks with a horizontal press of 1000 tons we have considered the three usual working conditions defined by Tables I., II., and III.

Table I.—Drawing of blanks after reheating of the punched blanks.

Table II.—Drawing of blanks after punching at the same heat.

Table III.—Drawing in the second die at the same heat of blanks punched and drawn in first die.

In each of these tables are indicated all the elements of the drawings carried out. The blanks are classed by order of the decrease in thickness of side before drawing. If we assume that

the average times of handling for each category are about the same for bringing the blank from the furnace to the die, it follows that our classification is equally a function of the decrease of temperature. It is evident, in fact, that the thinner the blank, the greater will be the cooling of the sides for same handling time.

For each of the drawings carried out we have given :

1. The dimensions, diameters, thickness, elongation.
2. The powers taken.
3. The values of ϕ and of R deduced from the powers taken and from the remaining and displaced section.
4. The values of P deducted from the value of R.

$$P = \frac{R}{1 + f \cot. \frac{\theta}{2}}$$

We have assumed $f = 0.35$, and we have calculated $\cot. \frac{\theta}{2}$ in relation to the connecting radii and of the diminution of the thickness of the side.

The connecting radii have been determined as indicated in Part I., paragraph IV. (c). Dies, 2nd type, Fig. 5.

At the end of each table are tabulated the ideal values of the connecting radii, which would have been convenient for each press taken. Assuming these radii we have determined the corresponding values of R and the power resulting from them, which are in some form the minimum under the conditions of temperature to which each of the drawings comply.

Table No. I.—Drawing of blanks after reheating of punched rough blanks.

If we compare the values of R we find they vary in larger proportions, and that for thin blanks R is four to five times larger than that for very thick blanks. That is easily explained.

1. The thin blanks become cold quicker than the thick ones for the same time of handling.

2. The contact with the finishing punch cools the thin blanks very quickly, whilst for thick ones the influence is scarcely appreciable.

3. The thin blanks take generally longer to draw, as the cooling increases in course of operation.

In the values found for R and deduced from the powers taken, there seems to be some anomalies. For example, for No. 21 $R=63.5$ kg., and for Nos. 23 and 24 $R=54.7$ kg. and 49 kg. For No. 21 the thickness of side before drawing was 17 mm., for Nos. 23 and 24 it was 14.75 mm. Logically, for the two latter R should be greater. The contrary is produced on account of the variation of $\cot. \frac{\theta}{2}$. For No. 21 the pass is very

feeble and $\cot. \frac{\theta}{2} = 8.65$, whilst for Nos. 23 and 24 the passes are heavier, and we have respectively $\cot. \frac{\theta}{2} = 6.64$ and 5.9.

From the above it is seen the influence of the ratio which must exist between the connecting radius of the die and the diminution of the thickness of the sides.

If we compare the values of p , calculated as indicated above, we find that they increase constantly and more and more with the diminution of the thickness of the sides.

In tabulating the ideal dies values of R similar to the values of p are evidently obtained.

Table No. II.—Drawing of blanks after punching at the same heat.

There again we find an increase of the value of p , with the decrease of the thickness of sides.

These values are slightly higher than those of Table I. for equal thickness of sides.

Also in Table I., for

$E = 90$	$p = 5.39$ kg.
$E = 61$	$p = 6.80$ kg.
$E = 53.5$	$p = 7.40$ kg.

and in Table II., for

$E = 91.5$	$p = 5.75$
$E = 62$	$p = 7.3$
$E = 52.5$	$p = 8.35$

This shows that for rough blanks drawn at the same heat after punching, the cooling of the walls is greater than in the first case.

The punching, however, is carried out at a temperature generally higher than that of drawing after reheating: the longer times of handling and the contact of the punching tool bring the blanks

at the moment of drawing to lower temperatures than those practised in the first case.

Table No. III.—Drawing in second die at the same heat of blanks punched and drawn in first die.

For equal thickness the difference between the values of p of this table and those of the preceding tables are more apparent. This difference increases as the thickness of the sides diminishes, which shows that the finishing punch has more action on the cooling of the rough blank, as the thickness of the latter becomes less.

In each table, if we compare the values of R obtained and those which are obtained on the basis of the ideal die, we determine the important rôle that the connecting radius plays in the power necessary.

In Fig. 11 we have traced the curves A, B, and C, representing the average values of p , for each of the drawing conditions previously mentioned.

They are established in relation to the thickness of the sides of the blanks before drawing.

It is seen that—

1. In each of the cases p increases rapidly as the thickness of side decreases.

2. The difference between the values of p in each case for a given thickness of sides increases as the thickness decreases.

It is certain that for a blank of a given thickness p can vary between the lower and higher limits of the curves, according to the temperature at which it is drawn. To remain within practical limits we have noted in each case the limits of the variations of power registered, which permits us to determine the corresponding values of p . These values are in the order of 0.9 to 1.1 p average. We have deduced from them zones A, B, C, which give the difference that we can practically allow for p in each of the cases and for the different thicknesses of sides.

In Fig. 12 we have traced the curves representing the resistance R to displacement in relation to the thickness of sides of the blanks before drawing.

These values in each of the cases are theoretical, and correspond to drawings taken by means of dies whose connecting

INVESTIGATION ON DRAWING.

(a) Curves showing amount of fluid pressure p per square mm. of the blank on the die during drawing in terms of the thickness of the walls before drawing.

References

A Curves showing the values of p for blanks reheated before drawing (Table 1)

B Curves showing the values of p for blanks punched and drawn through 1st die (Table 2)

C Curves showing the values of p for blanks punched and drawn through 2nd die after punching & drawing at same heat (Table 3)

b) ☒ A Your showing the variations of n occurring in practice for blanks reheated before drawing (Table 1)

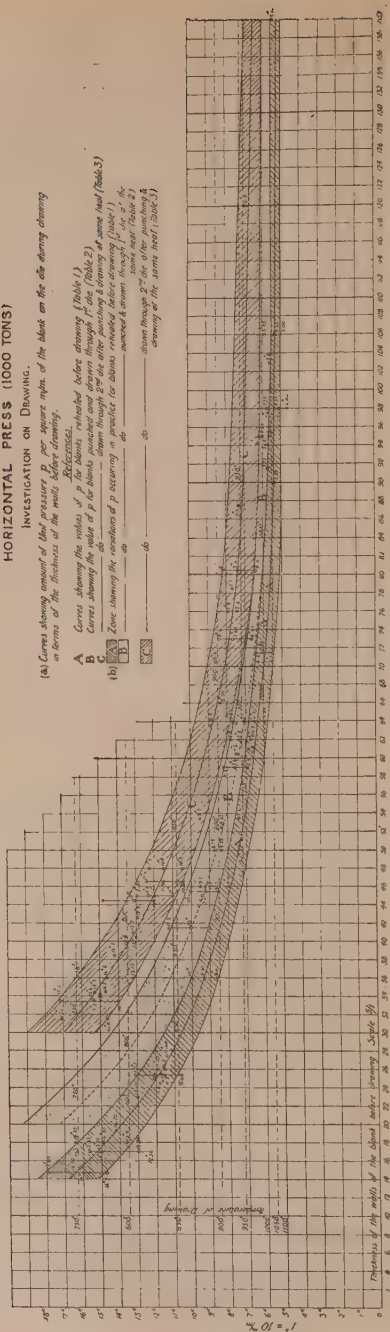
[illegible]

FIG. 11.

radius is equal to seven and a half times the diminution of the thickness of the side. They can therefore be considered as the minima.

IV. *Variation of the Strain ϕ and the Elongation.*

If the resistance to displacement R in a given section of die and a determined pass is solely a function of the thickness of sides of the blank or more exactly of the temperature, it is not the same for the strain ϕ sustained by the remaining section.

This strain varies according to the temperature at which the operation is made, but it is further a direct function of the elongation realised during the course of operation.

In fact, if we work on the same blanks, having the same dimensions and the same temperature before drawing, it is certain that the more important the pass, the more the strain carried by the remaining section will be increased.

The relation $\phi \times S = R \times s$ gives besides $\phi = \frac{R \times s}{S}$, therefore ϕ increases as $\frac{s}{S}$, that is to say, as the elongation, its variations can therefore be very considerable, from 0 for a zero pass up to the values capable of causing breakdown of the blank.

It is necessary to determine for a given thickness of side what is the maximum value that can be given to ϕ for a blank, in order that it will not break down during the course of operation.

1. *Maximum Values of ϕ .*—In Table No. I. are given some rather important drawings from the point of view of the elongations obtained. We have noted the cases which give signs of breakdown, or where breakdown takes place.

We have also indicated in Fig. 12 some maximum values of ϕ for different thicknesses of sides. We have afterwards traced the curve A' a little below the preceding values in such a manner that in taking for a given thickness the strain indicated by the curve, we are certain not to have breakdown.

Note.—It may appear abnormal that several blanks of the same dimensions appearing to be drawn under the same conditions, can in some cases act normally and in others present

either signs of breakdown or complete breakdown. This results from differences in their temperature.

Let us take, for example, a series of identical blanks at different temperatures, which we will draw in such a manner as to give the same elongation in the neighbourhood of the maximum possible.

All these blanks satisfy the condition $\frac{\phi}{R} = \text{constant}$ with ϕ in the neighbourhood of the breaking strain.

We have seen that R increases very rapidly with the lowering of temperature; from this it results that for a less hot drawing an increase in the power is necessary, from which often results a slowing down of the speed of the press, especially if the power of the latter is a little too exact.

The slowing down influences very little the temperature of the remaining section, but the zone of contact with the die becomes cooler. R increases very quickly and the value of ϕ becomes higher than the breaking strain.

This particular case is often met in practice, and it shows that to draw under good conditions it is necessary to have rapid and sufficiently powerful presses in order that the variations met in practice do not greatly influence the speed.

The maximum values of ϕ should appear to be in the neighbourhood of the figures for tensile resistance given above, since we have a tensile effort on the remaining section.

Nevertheless the figures which are given for the curve A and result from their manufacturing readings, are higher, especially for the small thicknesses; this is explained, on the one hand, by the fact that the punch cools the interior of the blank, resulting in an increase of the resistance of the metal; on the other hand, the rubbing of the blank on the punch which supports it produces a rubbing which allows it to carry a superior strain to that which it would support if free and submitted to an equal tensile force.

This action of the punch on the blank is naturally much more apparent the thinner the blank.

For very thick blanks the cooling is small and we can allow that the maximum strain ϕ is practically equal to the tensile strength at same temperature.

2. *Maximum Values of Elongation.*—The curve A' is practi-

cally parallel to the curve A, consequently the ratio $\frac{\phi}{R}$ (ϕ maximum) increases with the diminution of side before drawing. *In other words, the maximum elongation that can be given to a blank is as much greater as the blank is thinner.*

We have traced Fig. 12 in determining $\frac{\phi}{R}$ the curve A'_1 of the corresponding elongations, to the values of R and of ϕ from the curves A and A' (this curve A_1 refers to Table I.: blank drawn after reheating).

The increase is very slight for the very thick blanks, where the punch and the time of operation scarcely influence the cooling. With 70 millimetres thickness of sides the elongation possible increases more rapidly, afterwards bending and tending towards a limit of 70 per cent. to the small thicknesses.

In Tables II. and III. the elongations stated are not very numerous, which has prevented us determining the curves of the maximum values of ϕ , especially for points as we have done for A' in utilising Table I.

(For Table II. we had only some points, which have enabled us, however, to establish the curve B' .)

To aid us to construct the curves B' and C' we have indicated on the curves A, B, C, the drawing temperatures for intervals of 50°C . (At equal temperature R is constant whichever be the case taken.) We have therefore the points:

1A	1B	1C	for temperature =	800°
2A	2B	2C	" "	= 850°
3A	3B	3C	" "	= 900°
4A	4B	4C	" "	= 950°
5A	5B	" "	" "	= 1000°
6A	" "	" "	" "	= 1050°

Let us consider the points 1A, 1B, 1C, which correspond to drawings made at 800° .

The point 1A corresponds to a blank of 21 mm. in thickness.

"	1B	"	"	"	28.5	"	"
"	1C	"	"	"	41	"	"

Although these three drawings are made at the same temperature, the maximum strain ϕ that can be carried by each blank is not the same; the thinner, cooling quicker, can carry a strain

greater than the thick blank, which retains its heat better in the remaining section.

We have assumed that the strains $1b$ and $1c$ are a little less than the strain 1 as given by curve A' .

In doing the same for the points 2, 3, and 4, and in reducing each time the difference between the strains (which are normal, since as we attain the greater thicknesses the variations due to cooling are more feeble for an initial constant temperature), we have constructed the curves B' and C' and we have deduced from them the curve for the elongation B_1 and C_1 .

These two latter curves are similar to the curves A_1-B_1 and almost coincide with A_1 ; only the curve C_1 differs more than the two first. It should therefore be corrected in approaching it by others, since the values of ϕ of the curve C' are a little higher than the real ones, as this curve refers to blanks drawn in two dies for which the finishing punch becomes very hot and has less influence on the blank than in the two previous cases.

For reasons that we have just explained we allow as *practical curve of the maximum elongations in relation to the thickness of sides of the blanks before drawing, the curve A_1* .

The different elements of drawing for the particular case of large blanks are therefore well defined.

In order to extend this study to all cases Table IV. has been added, where are statements relative to some drawings of small and average blanks.

We have added to this table Fig. 13, which gives the representative curve in relation to the temperature of drawing.

- α . Some values of the unit pressure p of the blank on the die.
- A . Some values of the resistance to displacement R corresponding to drawings where the connecting radius of the die is equal to seven and a half times the diminution of the thickness of sides.

On the other hand, we have traced on Figs. 11 and 12 the scale of the temperatures of drawing. We can therefore, knowing the limits in which we must work for a blank, determine what will be the values of p , R , and ϕ .

To fix the ideas better, we will proceed to deal with the different problems which may present themselves in utilising the preceding.

V. Various Problems of Drawing.

1. We take a blank of internal diameter d , thickness of side E. This blank to be drawn in a horizontal press of 1000 tons to retain the internal diameter d , and in such a manner to obtain the

Curves showing in terms of the temperature of drawing

(a) The values of the unit pressure P of the blank on the die.

(A) The values of resistance to flow corresponding with drawing for which the radius of the rounded portion of the die is equal to $7\frac{1}{2}$ times the decrease in thickness of the walls.

(B) Values of the minimum fatigue Q that the residual area can withstand.

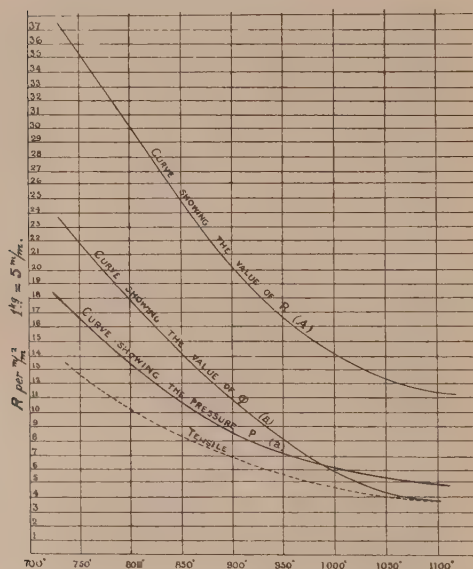


FIG. 13.

maximum elongation : it is required to determine the elements for operation.

(a) Assuming that the blank has just been *reheated* and that the stroke of the press allows to draw it in *two consecutive dies*.

(b) Assuming that the blank has just been *punched* and that the stroke of the press allows to draw it in *two consecutive dies*.

Let us take for example $d = 400$ mm., $E = 60$ mm. It is required in each case to determine the diameter of each die and

the connecting radius of the dies which will permit of the maximum elongation.

Case a.—Fig. 12 gives us for $E = 60$ mm. :

$$R = 15.2 \text{ kg. Curve A.}$$

$$\phi = 8.8 \text{ kg. Curve A'.$$

$$\text{Maximum elongation} = 45 \text{ per cent. } \frac{s}{S} = 0.45.$$

We have :

$$\text{Section of metal before drawing} \begin{cases} \text{External section (D = 520) = 212,500 mm.}^2 \\ \text{Interior section (d = 400) = 125,500 mm.}^2 \end{cases}$$

$$87,000 \text{ mm.}^2$$

Consequently :

$$\text{Remaining section S + section displaced } s = 87,000 \text{ mm.}^2$$

On the other hand :

$$\frac{s}{S} = 0.45 \text{ gives } s = 0.45 S,$$

from which :

$$S + 0.45 s = 87,000 \text{ mm.}^2 \text{ and } s = \frac{87,000}{1.45} = 60,000 \text{ mm.}^2$$

We have therefore :

$$\text{Section of 1st die} = (\text{Remaining section}) 60,000 + \text{section of punch } 125,500 \\ = 185,500 \text{ mm.}^2$$

The diameter of the first die will be 486 mm., and the thickness of sides remaining after the first die

$$\frac{486 - 400}{2} = 43 \text{ mm.}$$

The diminution realised in the course of the pass is 17 mm., consequently the die must have a connecting radius equal to $17 \times 7.5 = 128$ mm.

For the drawing in the second die, the thickness before drawing being 43 mm.; we can obtain an elongation of about 55 per cent. corresponding to $R = 22.5$ and $\phi = 12.6$ kg. These values are deduced from the curves B and B', for we can assume that the blank having been reheated before drawing is at the second die at the same conditions of temperature practically as those of a blank punched and drawn on the first die.

We have

$$s + S = 60,000 \text{ mm.}^2$$

$$\frac{s}{S} = 0.55.$$

Therefore

$$1.55 S = 60,000$$

$$S = \frac{60,000}{1.55} = 38,750 \text{ mm.}^2.$$

Which corresponds to a section of die equal to

$$125,500 + 38,750 = 164,250.$$

The diameter of the second die will be 458 mm., and the thickness of the remaining side $\frac{458-400}{2} = 29 \text{ mm.}$, and the diminution during the course of the pass 14 mm.

The connecting radius of the die is $14 + 7.5 = 105 \text{ mm.}$ The power necessary will be, with

$R = 15.2 \text{ kg.}$, $s = 27,000 \text{ mm.}^2$, $15.2 \times 27,000 = 410 \text{ tons}$ for the first die and with

$$R = 22.5 \text{ kg.}, s = 21,250 \text{ mm.}^2, 22.5 \times 21,250 = 480 \text{ tons for the second die.}$$

This last power is a little low, since in reality, although we have drawn the blank after reheating, the temperature at the pass in the second die is a little less than that which has been allowed for and which corresponds to $R = 22.5 \text{ kg.}$

Case b.—Since we have assumed that the curve of the maximum elongations in relation to the thickness of sides is uniform, the diameters and sections of dies will be the same as in the first case: only the powers necessary vary:

For the first die R	$= 17 \text{ kg.}$	Curve B.
and $P = 17 \times 27,000$	$= 460 \text{ tons.}$	
For the second die R	$= 29.5 \text{ kg.}$	Curve C.
and $P = 29.5 \times 21,250$	$= 625 \text{ tons.}$	

2. Given the same blank as before, it is required to draw it in the 1000-ton horizontal press in dies of which the section is determined in advance, the connecting radius being 200 mm.

It is required to determine the elements in the cases *a* and *b*.

This problem is different from the preceding one in that we only know ϕ .

R is definitely known, but only for a connecting radius which would be equal to seven and a half times the diminution of the thickness of the side.

In the preceding problem we have seen that in the case *a*, R is equal for the first die to 15.2 kg. To this resistance corre-

sponds an elongation of 45 per cent. and a diminution of thickness of sides of 17 mm. The connecting radius of the die which allows these figures to be obtained is 128 mm.

In the cases under discussion this radius would be 200 mm. If we allowed the same elongation as previously, that is to say, a diminution of thickness of sides of 17 mm., R would be equal to $p (1 + f \cot. \frac{\theta}{2})$, or $p = 6.6$ kg. after Fig. 11 (curve A), and

$$\cot. \frac{\theta}{2} = \sqrt{\frac{2r - \frac{D-d}{2}}{\frac{D-d}{2}}} = \sqrt{\frac{400 - 17}{17}} = 5.3,$$

consequently R would be equal to $6.6 (1 + 135 \times 5.3) = 18.9$ kg.

As the elongation is 45 per cent. we should have

$$\frac{\phi}{R} = 0.45, \text{ from which } \phi = 18.9 \text{ kg.} \times 0.45 = 8.5 \text{ kg.}$$

This value is well over that which is allowed, 6.8 kg., consequently if with the die of $r = 200$ mm. it is required to have the same elongation as with the die $r = 128$ mm., breakdown of the blank is certain to take place.

It is therefore necessary to determine the diminution of thickness of sides, so that for the value of R, and the corresponding elongation, we have $\phi = 6.8$ kg.

From the equation $R = p (1 + f \cot. \frac{\theta}{2})$ where $p = 6.6$ kg., and for $E = 60$ mm., we have :

$$R = 6.6 \text{ kg.} \left(1 + 35 \sqrt{\frac{2r}{E-e} - 1} \right) = 6.6 + 2.3 \sqrt{\frac{2c}{E-e} - 1}.$$

On the other hand—

$$\frac{s}{S} = \frac{S+s}{S} - 1,$$

$$\text{or } S + s \frac{\pi}{4} [(d + 2E)^2 - d^2] = \pi E (d + E).$$

If e is the thickness of the remaining sides, we have

$$S = \frac{\pi}{4} [(d + 2e)^2 - d^2] = \pi e (d + e).$$

Therefore

$$\frac{s}{S} = \frac{\pi E (d + E)}{\pi e (d + e)} - 1 = \frac{E (d + E)}{e (d + e)} - 1.$$

The equation $\frac{\phi}{R} = \frac{s}{S}$ became therefore

$$\frac{\phi}{R} = \frac{6.8}{6.6 + 2.3 \sqrt{\frac{c}{E-e} - 1}} = \frac{E(d+E)}{e(d+e)} - 1.$$

To solve this equation we are obliged to work by approximation.

We know already that $E - e$ must be less than 17 mm. Let us take, for example, $E - e = 15$ mm., we have $e = 60 - 15 = 45$ mm. The resistance R should have for value $R = 6.6 + 2.3 \frac{400}{15} - 1$, from which $R = 18.2$ kg.

The elongation corresponding to $E - e = 15$ will be

$$\frac{60(400 + 60)}{45(400 + 45)} - 1 = 0.37.$$

Consequently from $\frac{\phi}{R} = \frac{\phi}{18.2} = 0.37$, we have $\phi = 6.7$ kg.

The strain ϕ resulting from the pass indicated being a little inferior to the maximum strain, 6.8 kg., that can be allowed, the pass will be made without inconvenience. The elongation realised will be 37 per cent. instead of 45 per cent. in the first case. The diameter of the first die will be

$$520 - 30 = 490 \text{ mm.}$$

We will do the same for the second die. The thickness of sides before drawing is

$$\frac{490 - 400}{2} = 45 \text{ mm.}$$

The minimum resistance to displacement from curve B is 22 kg. and the maximum strain is 12 kg. (curve B').

The diminution of thickness of sides in the first case was 14 mm., and we had a connecting radius equal to 105 mm. Let us examine what ϕ becomes in making the diminution of the thickness of the sides equal to 11 mm., with a connecting radius equal to 200 mm.

We have

$$R = p \left(1 + 0.35 \sqrt{\frac{400}{11} - 1} \right) = 3.08 p,$$

or

$$p = 9.4 \text{ kg. (thickness 45 mm.)}$$

$$R = 9.4 \times 3.8 = 29 \text{ kg.}$$

The diminution of thickness of sides of 4 mm. corresponds to a unit elongation equal to :

$$\frac{E(d+E)}{e(d+e)} - 1 = \frac{45(400+45)}{34(400+34)} - 1 = 0.35.$$

As we must have

$$\begin{aligned}\frac{\phi}{R} &= 0.35, \\ \frac{\phi}{R} &= \frac{\phi}{29} = 0.35,\end{aligned}$$

from which

$$\phi = 10.2 \text{ kg.}$$

We have seen that ϕ could attain 12 kg. for this thickness of sides ; the pass that we have just established and verified appears a little low. In making $E - e = 12$ mm., we have :

$$R = 9.4 \left(1 + 0.35 \sqrt{\frac{400}{12} - 1} \right) = 28 \text{ kg.,}$$

and the elongation becomes :

$$\begin{aligned}\frac{45 \times 445}{35 \times 433} - 1 &= 0.4, \\ \frac{\phi}{R} = \frac{\phi}{28} &= 0.4,\end{aligned}$$

from which

$$\phi = 11.2 \text{ kg.}$$

This rate approaches more closely to the maximum 12 kg. It can be concluded that the elongation of 40 per cent. is acceptable and will not give rise to any incident.

The diameter of the second die will be :

$$490 - (12 \times 2) = 466 \text{ mm.}$$

The power necessary will be for the first die :

$$R \times s = 18.2 \text{ kg.} \times \frac{\pi}{4} (520^2 - 490^2) = 18.2 \times 24,000 = 435 \text{ tons,}$$

and for the second die :

$$R \times s = 28 \text{ kg.} \times \frac{\pi}{4} (490^2 - 466^2) = 28 \times 18,000 = 505 \text{ tons.}$$

In case *b* for drawing in the first die, we have ϕ maximum = 8 kg. (thickness 60 mm., curve B).

For a pass equal to that of case *a*, we have an elongation of 38 per cent. and R is equal to :

$$R = p(1 + 0.35 \times 5.05) = p \times 2.73.$$

p is equal to 7.5 after Fig. 11, curve B.

Therefore

$$R = 7.5 \times 2.73 = 20.5 \text{ kg.}$$

We have then

$$\frac{\phi}{R} = \frac{\phi}{20.5} = 0.38,$$

from which

$$\phi = 7.8 \text{ kg.}$$

This rate being inferior to the maximum 8 kg. allowed the pass can be effected without incident.

The die will be the same as for the preceding case, namely, $d = 490 \text{ mm.}$

For the second die we have ϕ maximum = 16 kg. (for a thickness = 45 mm., curve C, Fig. 12). With the same pass as before (die with $d = 466 \text{ mm.}$)—

$$R = p \times 3.08,$$

or

$$\begin{aligned} p &= 12.2 \text{ kg. (curve C, Plate I.).} \\ R &= 12.2 \times 3.08 = 37.6 \text{ kg.} \end{aligned}$$

We have

$$\frac{\phi}{R} = 6.4.$$

From which

$$\phi = 15 \text{ kg.}$$

This value is less than the maximum, consequently the pass can be made normally.

The power necessary per drawing will be for the first die :

$$p = 20.5 \times 24,000 = 490 \text{ tons,}$$

and for the second die :

$$p = 37.6 \times 18,000 = 680 \text{ tons.}$$

We have seen that the values of R are determined by :

$$R = p \left(1 + f \cot. \frac{\theta}{2} \right)$$

In the most favourable case, R minimum = $p + 2.31$. With a die of radius r we will write :

$$\frac{R}{R_{\min.}} = \frac{p \left(1 + f \cot. \frac{\theta}{2} \right)}{p \times 2.3}$$

Consequently :

$$R_1 = R \times \frac{1 + f \cot. \frac{\theta}{2}}{2.31} = R \times K.$$

When the thickness of sides and the temperature of drawing

are known, we can find R by means of Figs. 12 and 13. According to the die at our disposal the value of the resistance to displacement will immediately be found for a given pass, in multiplying R by the coefficient K corresponding.

In order to simplify the applications we give in Appendix a table of the values of K for the different connecting radii of die, and the diminution of thickness of sides obtained.

PART III.

SOME PRACTICAL CONSIDERATIONS.

Tables I., II., III., IV., which give the results, can serve as guides for the determination of the elements of drawing. Figs. 11, 12, and 13 permit the obtaining of what are the best working conditions; but we do not, however, neglect the practical side, and that is why we have given some observations which can be useful.

1. *Maximum Elongation*.—In a general manner it is better to keep a little below the maximum elongation obtainable. We can avoid the surprises which may be caused by large differences of temperature, and which we will enumerate below.

- (a) Slowing down of the press can produce breakdown, or, in case of limited power, the blockage of the blank in the die and on the punch.
- (b) Signs of breakdown in drawing of the blank, giving a diameter often smaller than that allowed for.
- (c) Staving of bottom of blank due to the retaining of the temperature in this thicker region. This accident is especially to be feared with punches very conical at the end, and in that case it is advisable to keep well below the maximum elongation. To ensure this, the maximum elongation corresponding to the thickest part of the wall should be adopted.
- (d) Contraction of the mouth of the blank, which is to be feared especially in the case of long and thin blanks, where the section is very cold when it arrives on the die.
- (e) Erosions and striation of dies, which are principally produced with blanks at a low heat.

2. *Dies*.—These should have, as nearly as possible, the ideal section indicated and should be very smooth and very hard.

Certain kinds of chilled cast iron with dressed surfaces give good results. The surfaces of blanks must be well cleaned outside and inside before drawing.

The dies must be abundantly lubricated with black grease. It is well to heat them at low temperature before putting in service, and to be sure of their perfect support in the die-carrier.

3. *Punches*.—The punches require every care both as to finish and to quality. The tensile strength should be 65 to 70 kg. per square millimetre, and tool marks or erosions should be avoided, as these greatly diminish their life.

The spraying after each press should be done regularly on all the surface and on the greatest length possible, in such a way as to avoid deformation.

Apply a mixture of tallow and blacklead, or of grease with blacklead, carefully over the punch before drawing, in order to prevent the blank adhering to it, and to facilitate the detachment.

4. *Thick Bottom*.—When the blanks have very thick bottoms it is necessary that the die should have a diameter slightly greater or equal to the external diameter of the bottom. It often occurs that when a blank is very eccentric it turns to the drawing without the die having touched it; if it is thick the torsion is often very important.

5. *Blanks of Internal Diameter larger than the Punch*.—When a blank has an internal diameter appreciably larger than that of the punch, the roughed blank must be treated very regularly; if not, the drawing tends to create more elongation in the hot part, which often diminishes the thickness and creates an eccentricity which did not exist before drawing.

6. *Drawing in several Dies simultaneously*.—Table IV. gives some examples of drawings in several dies. This procedure enables very large total elongations to be obtained. It is to be especially recommended in the case of blanks with very weak sides, and with some quick presses.

The pass must be divided out in such a manner that the work must be greatest at the first die and decrease successively on the others.

This method of operation also allows the stroke of the press to be reduced and diminishes the wear on the last die, which has only light work to carry out.

APPENDIX

TABLE GIVING THE VALUES OF K IN TERMS OF THE CURVATURE OF THE DIE AND OF THE PASSES MADE.

Curvature of Die. r.	Diminu- tion of Thickness of Walls. E - e.	f.	$\text{Cot. } \frac{\theta}{2} = \sqrt{\frac{2r}{E-e}} - 1$	$f \times \text{cot. } \frac{\theta}{2}$	$1 + f \text{cot. } \frac{\theta}{2}$	$K = \frac{1 + f \text{cot. } \frac{\theta}{2}}{2.31}$
50	4	0.35	6.25	2.18	3.18	1.37
	5	"	5.56	1.94	2.94	1.27
	6	"	5.06	1.77	2.77	1.20
	7	"	4.67	1.63	2.63	1.14
	8	"	4.35	1.52	2.52	1.09
	9	"	4.09	1.43	2.43	1.05
	10	"	3.87	1.35	2.35	1.02
90	4	0.35	6.65	2.33	3.33	1.45
	5	"	5.91	2.07	3.07	1.33
	6	"	5.38	1.88	2.88	1.24
	7	"	4.97	1.74	2.74	1.18
	8	"	4.64	1.62	2.62	1.13
	9	"	4.36	1.53	2.53	1.10
	10	"	4.12	1.44	2.44	1.05
100	11	"	3.91	1.37	2.37	1.025
	12	"	3.74	1.31	2.31	1.000
100	4	0.35	7.00	2.45	3.45	1.49
	5	"	6.25	2.18	3.18	1.37
	6	"	5.68	1.98	2.98	1.29
	7	"	5.25	1.84	2.84	1.23
	8	"	4.09	1.72	2.72	1.18
	9	"	4.06	1.61	2.61	1.13
	10	"	4.35	1.52	2.52	1.09
110	11	"	4.15	1.45	2.45	1.06
	12	"	3.96	1.38	2.38	1.03
	13	"	3.78	1.32	2.32	1.00
<i>Radius of Curvature of Die, r = 110 millimetres.</i>						
110	4	0.35	7.35	2.57	3.57	1.54
	5	"	6.55	2.30	3.30	1.47
	6	"	5.96	2.08	3.08	1.34
	7	"	5.54	1.94	2.94	1.27
	8	"	5.15	1.80	2.80	1.21
	9	"	4.85	1.70	2.70	1.17
	10	"	4.60	1.61	2.61	1.13
110	11	"	4.35	1.52	2.52	1.09

Curvature of Die. r .	Diminu- tion of Thickness of Walls, $E - e$.	f .	$\text{Cot. } \frac{\theta}{2} =$ $\sqrt{\frac{2r}{E - e} - 1}$	$f \times \text{cot. } \frac{\theta}{2}$	$1 + f \text{cot. } \frac{\theta}{2}$	$K =$ $\frac{1 + f \text{cot. } \frac{\theta}{2}}{2.31}$
<i>Radius of Curvature of Die, $r = 110$ millimetres (continued).</i>						
110	12	0.35	4.15	1.47	2.47	1.07
	13	"	3.98	1.38	2.38	1.03
	14	"	3.83	1.34	2.34	1.01
<i>Radius of Curvature of Die, $r = 120$ millimetres.</i>						
120	4	0.35	7.70	2.70	3.70	1.60
	5	"	6.85	2.40	3.40	1.47
	6	"	6.30	2.20	3.20	1.39
	7	"	5.75	2.02	3.02	1.30
	8	"	5.40	1.89	2.89	1.24
	9	"	5.08	1.77	2.77	1.19
	10	"	4.80	1.68	2.68	1.16
	11	"	4.60	1.61	2.61	1.13
	12	"	4.35	1.52	2.52	1.09
	13	"	4.17	1.46	2.46	1.07
	14	"	4.05	1.41	2.41	1.05
	15	"	3.86	1.35	2.35	1.02
	16	"	3.74	1.31	2.31	1.00
<i>Radius of Curvature of Die, $r = 130$ millimetres.</i>						
130	4	0.35	8.00	2.80	3.80	1.64
	5	"	7.15	2.50	3.50	1.52
	6	"	6.50	2.28	3.28	1.46
	7	"	6.00	2.10	3.10	1.34
	8	"	5.60	1.96	2.96	1.28
	9	"	5.30	1.86	2.86	1.24
	10	"	5.00	1.75	2.75	1.19
	11	"	4.75	1.66	2.66	1.15
	12	"	4.55	1.59	2.59	1.12
	13	"	4.35	1.52	2.52	1.09
	14	"	4.20	1.47	2.47	1.07
	15	"	4.05	1.41	2.41	1.05
	16	"	3.90	1.37	2.37	1.03
<i>Radius of Curvature of Die, $r = 140$ millimetres.</i>						
140	4	0.35	8.35	2.92	3.92	1.70
	5	"	7.45	2.61	3.61	1.56
	6	"	6.75	2.37	3.37	1.45
	7	"	6.25	2.18	3.18	1.37
	8	"	5.82	2.05	3.05	1.32
	9	"	5.50	1.93	2.93	1.27
	10	"	5.19	1.81	2.81	1.21
	11	"	4.94	1.73	2.73	1.18
	12	"	4.72	1.65	2.65	1.14
	13	"	4.52	1.58	2.58	1.11
	14	"	4.36	1.53	2.53	1.09
	15	"	4.20	1.47	2.47	1.07

Curvature of Die. r .	Diminu- tion of Thickness of Walls. $E - e$.	f .	$\text{Cot. } \frac{\theta}{2} =$ $\sqrt{\frac{2r}{E - e} - 1}$	$f \times \text{cot. } \frac{\theta}{2}$	$1 + f \text{cot. } \frac{\theta}{2}$	$K =$ $\frac{1 + f \text{cot. } \frac{\theta}{2}}{2.31}$
<i>Radius of Curvature of Die, $r = 140$ millimetres (continued).</i>						
140	16	0.35	4.06	1.42	2.42	1.05
	17	"	3.94	1.38	2.38	1.03
	18	"	3.81	1.32	2.32	1.01
<i>Radius of Curvature of Die, $r = 150$ millimetres.</i>						
150	4	0.35	8.61	3.02	4.02	1.74
	5	"	7.68	2.68	3.68	1.58
	6	"	6.99	2.44	3.44	1.48
	7	"	6.62	2.32	3.32	1.44
	8	"	5.96	2.09	3.09	1.33
	9	"	5.70	2.00	3.00	1.30
	10	"	5.38	1.88	2.88	1.24
	11	"	5.12	1.80	2.80	1.21
	12	"	4.90	1.72	2.72	1.16
	13	"	4.70	1.64	2.64	1.14
	14	"	4.52	1.58	2.58	1.11
	15	"	4.36	1.53	2.53	1.09
	16	"	4.21	1.48	2.48	1.07
	17	"	4.09	1.43	2.43	1.05
	18	"	3.97	1.39	2.39	1.03
	19	"	3.85	1.35	2.35	1.01
	20	"	3.74	1.31	2.31	0.99
<i>Radius of Curvature of Die, $r = 160$ millimetres.</i>						
160	4	0.35	8.90	3.11	4.11	1.77
	5	"	7.82	2.85	3.85	1.66
	6	"	7.23	2.54	3.54	1.52
	7	"	6.70	2.35	3.35	1.45
	8	"	6.24	2.19	3.19	1.37
	9	"	5.87	2.05	3.05	1.32
	10	"	5.57	1.94	2.94	1.27
	11	"	5.29	1.85	2.85	1.23
	12	"	5.07	1.78	2.78	1.20
	13	"	4.86	1.70	2.70	1.17
	14	"	4.68	1.64	2.64	1.14
	15	"	4.51	1.58	2.58	1.11
	16	"	4.35	1.52	2.52	1.09
	17	"	4.22	1.48	2.48	1.07
	18	"	4.10	1.43	2.43	1.05
	19	"	3.98	1.39	2.39	1.03
	20	"	3.86	1.35	2.35	1.01
	21	"	3.78	1.32	2.32	1.00
<i>Radius of Curvature of Die, $r = 170$ millimetres.</i>						
170	4	0.35	9.16	3.20	4.20	1.81
	5	"	8.20	2.86	3.86	1.67
	6	"	7.45	2.60	3.60	1.56

Curvature of Die. r .	Diminu- tion of Thickness of Walls. $E = e$.	f .	$\cot. \frac{\theta}{2} =$ $\sqrt{\frac{2r}{E - e} - 1}$	$f \times \cot. \frac{\theta}{2}$	$1 + f \cot. \frac{\theta}{2}$	$K =$ $\frac{1 + f \cot. \frac{\theta}{2}}{2.31}$
<i>Radius of Curvature of Die, $r = 170$ millimetres (continued).</i>						
170	7	0.35	6.90	2.41	3.41	1.47
	8	"	6.54	2.30	3.30	1.43
	9	"	6.06	2.12	3.12	1.35
	10	"	5.75	2.01	3.01	1.31
	11	"	5.46	1.91	2.91	1.26
	12	"	5.23	1.84	2.84	1.22
	13	"	5.00	1.76	2.76	1.19
	14	"	4.82	1.69	2.69	1.16
	15	"	4.65	1.63	2.63	1.13
	16	"	4.50	1.58	2.58	1.11
	17	"	4.36	1.53	2.53	1.09
	18	"	4.23	1.48	2.48	1.07
	19	"	4.12	1.44	2.44	1.05
	20	"	4.00	1.40	2.40	1.03
	21	"	3.82	1.34	2.34	1.01
<i>Radius of Curvature of Die, $r = 180$ millimetres.</i>						
180	4	0.35	9.45	3.30	4.30	1.86
	5	"	8.65	3.01	4.01	1.74
	6	"	7.70	2.70	3.70	1.60
	7	"	7.10	2.49	3.49	1.51
	8	"	6.65	2.33	3.33	1.44
	9	"	6.25	2.18	3.18	1.37
	10	"	5.82	2.05	3.05	1.32
	11	"	5.62	1.98	2.98	1.28
	12	"	5.57	1.86	2.86	1.24
	13	"	5.18	1.81	2.81	1.21
	14	"	4.98	1.74	2.74	1.18
	15	"	4.80	1.68	2.68	1.16
	16	"	4.65	1.63	2.63	1.13
	17	"	4.50	1.58	2.58	1.11
	18	"	4.36	1.53	2.53	1.09
	19	"	4.24	1.48	2.48	1.07
	20	"	4.13	1.44	2.44	1.05
	21	"	4.01	1.41	2.41	1.04
	22	"	3.91	1.37	2.37	1.03
	23	"	3.82	1.33	2.33	1.01
<i>Radius of Curvature of Die, $r = 190$ millimetres.</i>						
190	4	0.35	9.70	3.40	4.40	1.90
	5	"	8.65	3.05	4.05	1.75
	6	"	7.70	2.72	3.72	1.61
	7	"	7.30	2.55	3.55	1.54
	8	"	6.82	2.40	3.40	1.47
	9	"	6.53	2.30	3.30	1.42
	10	"	6.10	2.12	3.12	1.35
	11	"	5.79	2.02	3.02	1.31
	12	"	5.54	1.94	2.94	1.27

TABLE I.—1000-Ton Press. Drawing after Reheating of Pierced Blanks.

Before Drawing										Elongation.		Pressures Attained.			Pressures Attained.			ϕ by mm ² . of S.			R by mm ² . of S.			Thickness of Walls Left.	Reduction of Walls $\frac{D-d}{2}$	Radius of Curve of Die.	$\cot \theta = \frac{D-d}{2r} = \frac{r}{\frac{D-d}{2}}$	$\frac{1}{f \cot \theta}$	$\frac{R}{1 + f \cot \theta}$			Based on: $f = 0.35$ and $\cot \theta = 3.75$.			Notes.	
Diam. Ext. S.	Diam. Int. F.	Section of Metal, S.	Thick-ness of Walls, s.	Vm.	Mm.	Mm ²	Mm ²	%	%	Kg.	Kg.	Kg.	Tons.	Tons.	Tons.	Kg.	Kg.	Kg.	Kg.	Kg.	Kg.	Min.	Average.						Max.	Min.	Average.	Max.	Min.	Average.		Max.
1	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
2	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
3	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
4	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
5	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
6	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
7	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
8	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
9	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
10	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
11	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
12	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
13	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
14	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
15	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
16	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
17	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
18	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
19	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
20	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
21	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
22	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
23	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			
24	100	100	11000	10	100	100	11000	10	11.1	1050	215	235	350	375	410	2.46	2.64	2.80	11.5	12.25	13.5	90	16	120	3.75	0.35	9.31	4.64	5.3	5.85	131	12.25	375			

TABLE III.—1000-Ton Press. Drawn through Second Die, on one Heat, with Punched Blank.

[illegible]

TABLE IV.—1000-Ton Press. *Different Drawings on Various Die Presses.*

[illegible]

¹ E.S. signifies: Explosive shell.

* 1st heat.

2nd heat.

4 3rd heat.

* 1st heat.

* 2nd heat.

$$f = \frac{\text{Curvature of Die. } r.}{\text{Diminution of Thickness of Walls. } E - e.} = \frac{\text{Cot } \theta}{\sqrt{\frac{2r}{L - e}}} = \frac{1}{\sqrt{\frac{2r}{L - e}}} \times \frac{1}{\tan \theta} = \frac{1}{\sqrt{\frac{2r}{L - e}}} \times \frac{1}{\frac{1}{\sqrt{1 - \frac{e}{L}}}} = \frac{1}{\sqrt{\frac{2r}{L - e} \times \frac{1}{1 - \frac{e}{L}}}} = \frac{1}{\sqrt{\frac{2r}{L - e} \times \frac{L}{L - e}}} = \frac{1}{\sqrt{\frac{2rL}{(L - e)^2}}} = \frac{L - e}{\sqrt{2rL}}$$

Radius of Curvature of Die, $r = 190$ millimetres (continued).

190	13	0.35	5.32	1.86	2.86	1.21
	14	"	5.12	1.79	2.79	1.20
	15	"	4.92	1.72	2.72	1.17
	16	"	4.77	1.67	2.67	1.15
	17	"	4.62	1.62	2.62	1.13
	18	"	4.50	1.58	2.58	1.11
	19	"	4.37	1.53	2.53	1.09
	20	"	4.25	1.49	2.49	1.08
	21	"	4.13	1.44	2.44	1.06
	22	"	4.04	1.41	2.41	1.04
	23	"	3.94	1.38	2.38	1.03
	24	"	3.86	1.35	2.35	1.02

Radius of Curvature of Die, $r = 200$ millimetres.

200	4	0 35	3-50	4-50	1-95
	5	"	8-10	3-12	1-78
	6	"	8-10	3-82	1-66
	7	"	7-50	3-62	1-56
	8	"	7-00	3-45	1-49
	9	"	6-61	3-32	1-44
	10	"	6-25	3-18	1-38
	11	"	5-95	3-08	1-33
	12	"	5-68	2-98	1-29
	13	"	5-46	2-91	1-26
	14	"	5-25	2-84	1-23
	15	"	5-07	2-78	1-20
	16	"	4-90	2-72	1-17
	17	"	4-75	2-66	1-14
	18	"	4-61	2-62	1-12
	19	"	4-48	2-57	1-11
	20	"	4-36	2-53	1-09
	21	"	4-25	2-49	1-08
	22	"	4-15	2-45	1-06
	23	"	4-05	2-42	1-04
	24	"	3-96	2-39	1-03
	25	"	3-88	2-36	1-02
	26	"	3-79	2-33	1-01

Iron and Steel Institute.

THE MANUFACTURE OF SHELLS IN CANADA DURING THE WAR 1914-1918.

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IN putting forward this paper the authors have felt that, although the subject-matter was concerned with circumstances now happily long past, some notes on the part played by one of the Dominions in helping to meet the huge demand for ammunition during the war might usefully be placed on record in the Journal of the Institute. Many of the methods employed did not differ materially from those used in England, but interesting variations were introduced by manufacturers casting small ingots to combine large production with accepted sound methods of casting. The method of inspection is referred to, and some statistics have been compiled. Other matters of more general interest dealt with include heat treatment, the Sandberg air treatment, and the types of defects found in shell steel.

MANUFACTURE AND FORM OF PRODUCT.

Steel-making Processes.

Steel for shell was produced in Canada by the following processes, in approximately the percentages given :

	Per Cent.
Basic open-hearth	65·6
Acid open-hearth	25·8
Basic electric	7·8
Acid electric	0·7
Bessemer	0·1

The basic open-hearth steel was practically all cast into ingots of about 3 tons weight. These were either rolled into blooms and later reheated for rolling into bar, or rolled into bar direct. The former method was preferable, in that it allowed the removal of surface defects before the bar approached the size of the actual shell. Basic steel provided all the material for 18-pdr. H.E. and shrapnel shell, while all the processes mentioned

were used for steel for other natures of shell. Most of the steel made by other processes was cast in small ingots for forging direct into shell. A small amount of acid open-hearth and basic electric steel was made in the form of rolling-mill ingots from 800 to 1300 lbs. in weight.

The first contracts (for small natures of shrapnel) were placed in October 1914.

The following table gives the approximate distribution of the forgings supplied, and the weight of steel estimated from the average weight of the blanks:

Size of Shell.	Number.	Average Weight per Blank.	Estimated Weight of Steel.
15-pdr. sh. forgings .	Canadian 306,696	Lbs. 13	Tons. 1,780
18-pdr. H.E. shell .	„ 5,910,881	27	71,272 ¹
18-pdr. sh. forgings .	Canadian 37,185,370	14	232,408
	American 811,246		5,070
	Total 37,996,616		237,478
4·5-inch H.E.forgings .	Canadian 16,741,514	54	403,590
	American 1,100,024		26,518
	Total 17,841,538		430,108
60-pdr. H.E. forgings .	Canadian 1,064,053	87	41,327
	American 152,591		5,926
	Total 1,216,644		47,253
6-inch H.E. forgings .	Canadian 13,718,073	155	949,241
	American 663,733		45,928
	Total 14,381,806		995,169
8-inch H.E. forgings .	Canadian 573,801	275	70,432
	American 282,332		34,661
	Total 856,133		105,093
9·2-inch H.E. forgings	Canadian 537,986	390	93,667
	American 333,919		58,584
	Total 871,905		152,251
Total Canadian . . .		1,863,717 tons	
Total American . . .		176,687 „	
Grand total . . .		2,040,404 „	

¹ Estimated as number of shell delivered plus 5 per cent. for losses in machine shop.

In addition an estimate is given below of the quantity of steel used for adapters, base plates, and discs :

	Number.	Average Weight.	Total Weight.
			Tons.
Discs for shrapnel shell . . .	38,303,312	8 oz.	8,638
Base plates for 18-pdr. H.E. shell	5,629,411	12 „	1,884
Base plates for 4.5-inch and 60-pdr. shell . . .	19,058,182	1.6 lbs.	13,613
Base plates for 6-inch shell . .	14,381,806	3.5 „	22,471
Adapters for 8-inch shell . . .	856,033	26 „	9,936
Adapters for 9.2-inch shell . .	871,905	44 „	17,126
		Total .	73,668

The above estimate includes the bulk of the steel used in components with the exception of steel nose bushes, a record of the number of which is not available. Most of these components were produced in Canada, except about 10,000 tons of adapters, which were forged in the U.S.A.

The total quantity of steel used in Canadian orders can therefore be summarised as follows :

	Manufactured in Canada. Tons.	Manufactured in U.S.A. Tons.
Used in shell forgings . . .	1,863,717	176,687
Used in components . . .	73,668	10,000
Total . . .	1,937,385	186,687
Grand total . . .	2,114,072 tons.	

The approximate quantity of steel produced in Canada for the above forgings and components was 1,737,000 tons, and the balance of about 200,000 tons was received from the U.S.A. in the form of bars or blooms, and forged in Canada.

Methods of Manufacture.

(a.) 18-pdr. H.E. Shell.—These shell were made by boring from the solid billet cut from rolled bar. The final mechanical tests of the steel were taken at the rolling-mill, and the acquirement of the necessary properties was thus dependent to a large extent on the treatment received in the rolling and during the subsequent cooling. If the manufacturer so desired the bars might be normalised or annealed (*i.e.*, raised to a temperature

just above the upper limit of the critical range and cooled in air or in the furnace respectively), but little steel was so treated, owing to the lack of suitable furnaces and the cost of such treatment. Manufacturers experienced difficulty in finishing rolling in such a way that the steel gave both the yield point and the elongation required. The conditions were somewhat eased later by the reduction of the specified elongation from 17 to 14 per cent., when the maximum stress was not less than 40 tons per square inch.

(b.) *Other Natures of Shell*.—All shell other than 18-pdr. H.E. were machined from hollow forgings made by punching, followed in some instances by a drawing operation. The billets, generally in the form of small ingots, were made slightly smaller in diameter than the final forging in order to fit easily into the die of the press.

Ingots for Direct Forging.

A. *Form*.—At the commencement of H.E. shell steel manufacture a number of foundries cast the small ingots for 4·5, 60-pdr., and 6-inch shell of sufficient length to make two billets after removal of the discard of 20 per cent. The length of such ingots was large in proportion to the cross sectional area, and a large percentage of ingots showed secondary piping. This type was eventually abandoned and replaced by a shorter ingot form, from which only one shell could be made.

8-inch and 9·2-inch shells were forged with solid nose and open base. It was therefore possible, for this type of shell, to cast tapered ingots wide end up (see Fig. 1), and sound steel, free from secondary piping, was produced. For natures of shell forged with solid base the use of a tapered ingot was at first thought to be impracticable, but in one instance a maker adopted a special design of ingot which was cylindrical for about 4 inches from the top, then tapered to the base, which was almost a square, in such a way that the diagonal of the square was equal to the diameter of the cylindrical portion (see Fig. 2). Secondary piping was avoided and no trouble was experienced in forging. Subsequently a uniformly tapered ingot was successfully tried for 6-inch shell, and this form was then generally adopted, though it necessitated the making of a slightly heavier forging to give

sufficient margin for the removal of the radius left at the corner of the base (see Fig. 3). The use of tapered ingots for shell other than 6-inch was not made compulsory for the reason that,

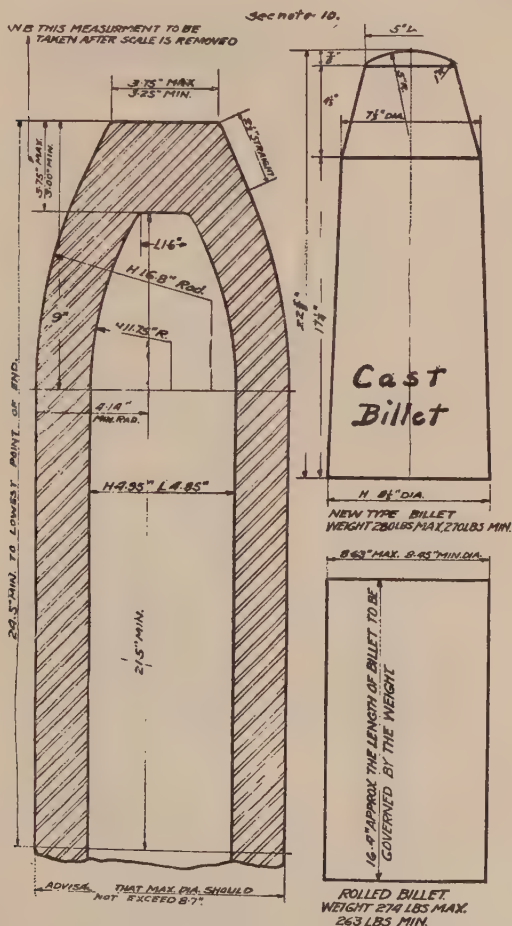


FIG. 1.—Forging and Billet. Shell, B.L., H.F., 8-inch howitzer, Mk. V. (L.).

although at some plants unsoundness was much in evidence in parallel ingots, at others rejections from this cause were very low. With the adoption of tapered ingots for 6-inch shell the rejections decreased at some plants to less than 1 per cent., the

general average being about 3 to 5 per cent. from all causes. Surface defects gave rise to heavy rejections at one or two plants.

B. *Moulds and Sinking Heads*.—The shape of the forgings

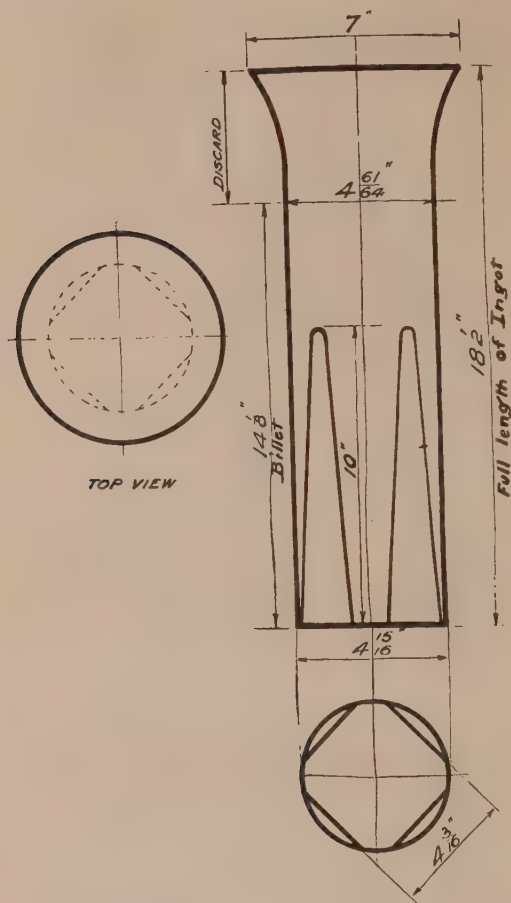


FIG. 2.—Special Design of Cast Steel Billet for 4.5-inch Shells.

for 8-inch and 9·2-inch shell required a mould with a solid bottom, but for all other natures open moulds were employed. Both brick and sand heads were used, mainly the latter. The design varied at different plants, but generally the head was slightly less in internal diameter than the ingot, and in some cases was

provided with a lip which fitted the top of the mould closely. Typical moulds and sinking heads are shown in Figs. 4 and 5. Both cast iron and steel stools were used with open bottom moulds, and a layer of thick paper was generally laid on the stool,

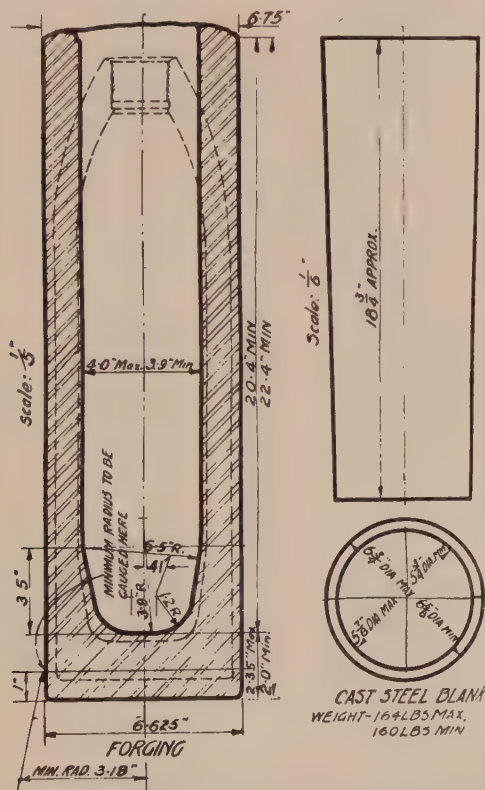


FIG. 3.—Forging and Cast Steel Blank. Shell, B.L., H.E., 6-inch howitzer light. Mks. III, XI, and XIII.

before casting, to prevent burning. Mould washes of all kinds, such as silica, lime, and tar, were tried, but it was generally considered that the best ingot surface was obtained without any wash.

Large Ingots for Rolling.—Casting from a bottom-stoppered ladle, having a nozzle 1 to $1\frac{3}{4}$ inches diameter, was the general practice. All ingots were top poured. Brick sinking heads

were in use in some places. The tapered ingot, cast with large

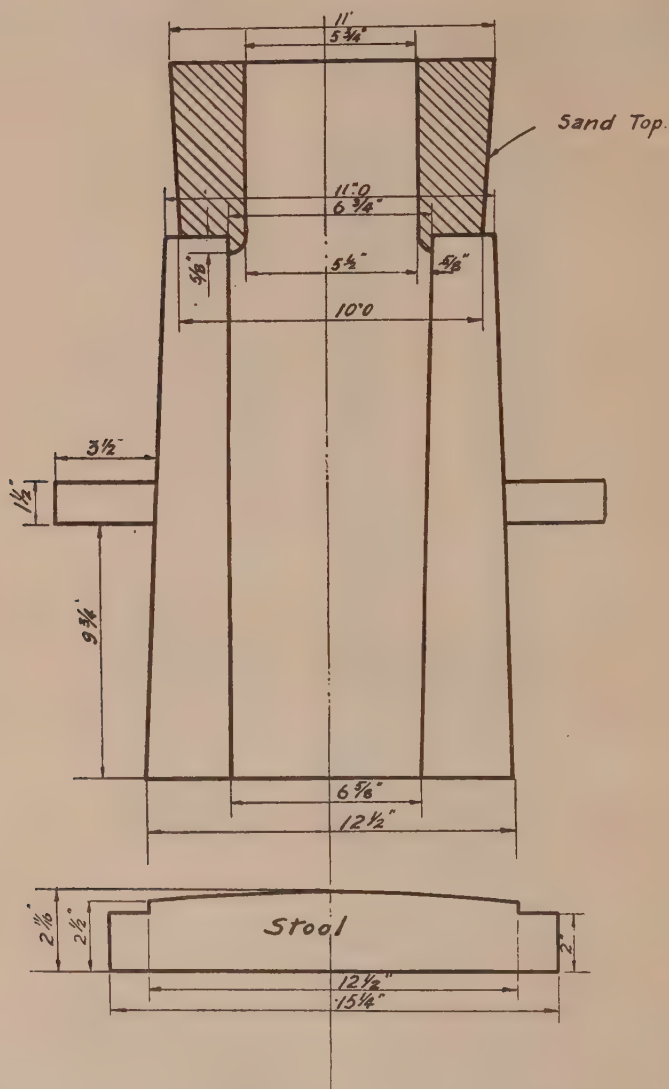


FIG. 4.—Open Bottom Mould for 6-inch Shell Ingot.

end uppermost, was strongly recommended to manufacturers, but was not adopted in Canada at any of the plants casting large

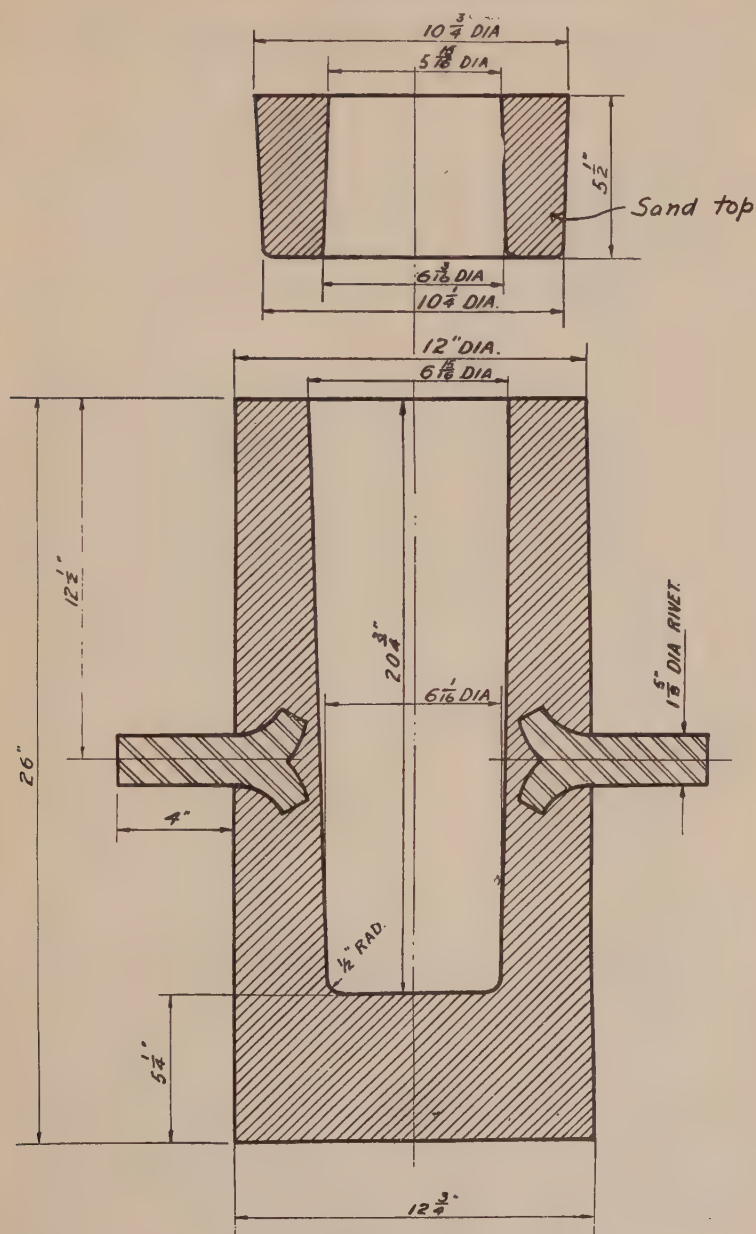


FIG. 5.—Solid Bottom Mould for 6-inch Shell Ingot.

ingots for rolling, the manufacturers anticipating difficulty in stripping the moulds and objecting to the cost of an entire change of equipment.

Deoxidising by means of aluminium was discouraged as a general practice, and at one of the largest plants its use was almost entirely discontinued. In a few instances ferro-carbon-titanium was added to the ladle. Practically in no instance did the aluminium content of the steel exceed the maximum of 0.05 per cent. permitted and titanium varied from a trace to a maximum of 0.017 per cent.

Forgings and Treatment.—The presses used for forging varied in power from 200 to 1000 tons. A 350-ton press was generally used for 6-inch and a 500-ton press for 9.2-inch shell. The billets were heated in either continuous or oven furnaces, fired in the majority of cases by oil, but sometimes by coal. Manufacturers were recommended to “set-down” the billet (*i.e.* to compress the billet into contact with the die by means of a flat ended tool) before punching. This operation reduces the risk of producing eccentric forgings, but the makers, with very few exceptions, failed to adopt it because of the additional time and expense involved. The rate of production per press per hour varied considerably. The average and maximum output per hour of a few types are given below:

	Average.	Maximum.
18-pdr. shrapnel	120	187
4.5-inch H.E. shell	79	100
6-inch H.E. shell	51	125
9.2-inch H.E. shell	50	77

The figures above refer to single punch presses. Greater output was possible with presses having multiple punches, used by a few firms for forging the smaller types of shell.

It was recommended that forgings should be cooled either by standing on end on the floor separated by an air space or suspended upside down on iron pegs. The stacking of hot forgings was liable to result in irregular mechanical properties, owing to the partial annealing of the inside forgings, and was discouraged. The consequences of faulty cooling treatment could generally be corrected by normalising. There were certain heats, however, which failed to meet the required mechanical tests after

normalising. At one time a water treatment, consisting in the filling of the hot forging, stood on its base, with water, was

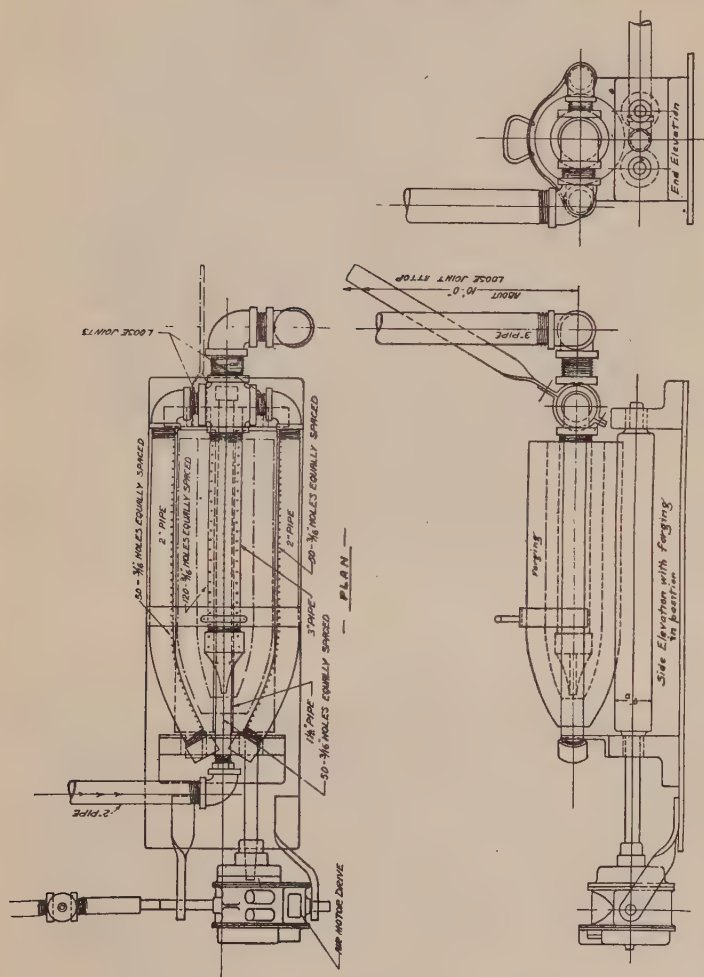


FIG. 6.—Apparatus for Air Cooling.

introduced. After evaporation of the water the walls of the forging were generally at a black heat. Some improvement resulted, but mechanical tests gave irregular results, even in tests from the same forging, and eventually permission to use the treatment was withdrawn.

Air Cooling.—The Sandberg air-cooling process, which was authorised for use in 1917, consists in the accelerated cooling of the forging from about 850°C. to black heat by means of an air-blast. The application of this process for the hardening of rails is well known, and its use for shell forgings was lent free to the British Government by Messrs. Sandberg of London, for the duration of the war. Various designs of apparatus were in use, the majority using low pressure blast. The two principal types are described below: (1) The forging was revolved on rollers and air-blast was supplied by perforated pipes, two outside and one inside the forging. The apparatus of this type used by the Canada Cement Company and others is shown in Fig. 6. (2) The forging was placed in an iron jacket having a hinged top. The jacket was of sufficient size to allow an air space round the forging, which rested on a number of studs fixed in the jacket. Air-blast was applied by means of a telescopic pipe to the interior and by direct supply to the jacket to the exterior of the forging. Both perforated and open-ended pipes were used. The air pressure used at the different plants varied considerably, the average being from 8 to 12 ounces per square inch. The time required for cooling a 6-inch forging was from four to eight minutes.

The results obtained by the air-cooling treatment were most satisfactory. A total of 563,688 forgings were treated, the rejections on subsequent mechanical testing being only 16,055, about 2·8 per cent. It was found as a rule that the yield point could be raised 2 to 3 tons and the maximum stress 4 to 5 tons per square inch by air-cooling, the elongation usually not being reduced to any appreciable extent. The forgings from a number of heats of steel low in carbon and manganese were air-cooled direct from the forging press.

INSPECTION AND DEFECTS IN SHELL STEEL.

Composition.—The inspection and keeping of records commenced at the melting furnaces. The last ingot poured in each heat was marked for chemical analysis, and, as a check on uniformity, samples were taken once a week from the first, middle, and last ingot of a heat. High phosphorus in the last

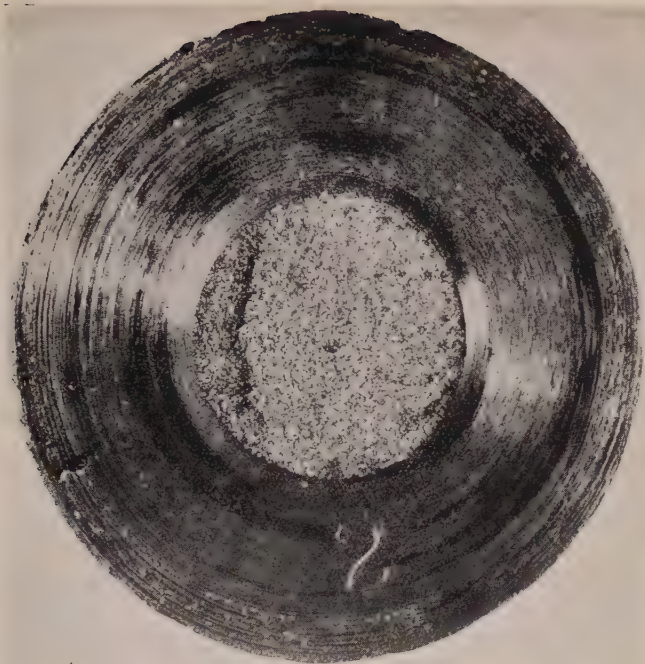


FIG. 7. Top of 4.5" Cast Billet showing piping after removal of discard by parting and fracturing.

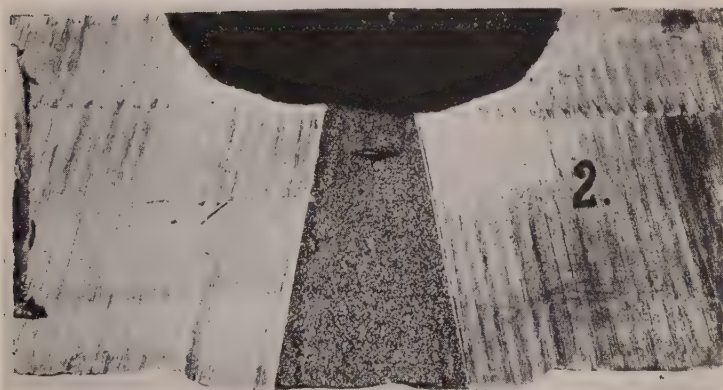


FIG. 8. Base of 4.5" Forging made from billet shown in Fig. 7.
The presence of piping is clearly visible.

[To face p. 240.

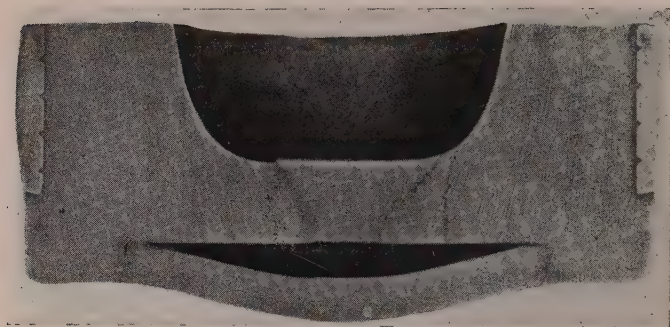


FIG. 9.

Typical Loose Cone in base of 60-pr. shell, which showed bulging of base-plate after hydraulic testing. Macro-etched.



FIG. 10.

Structure near line of cone separation showing area of phosphide eutectic.

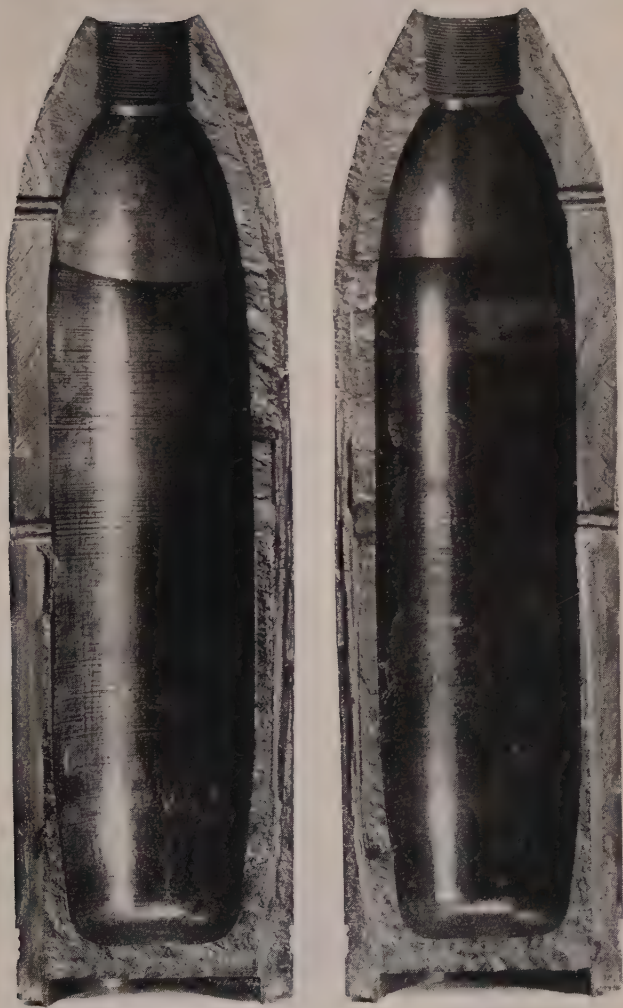


FIG. 11.

6-inch Shell which burst under hydraulic test.

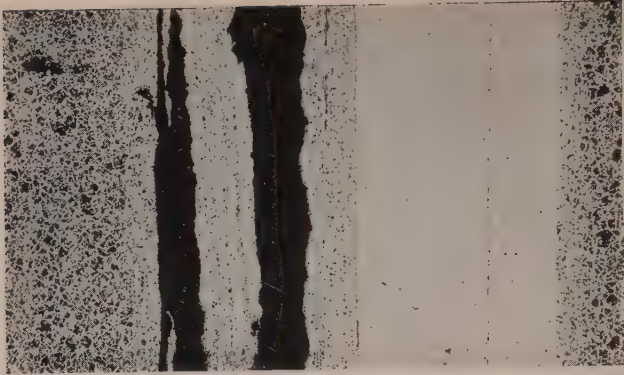


FIG. 12.

Longitudinal section through defective region showing slag seams and decarburised areas.

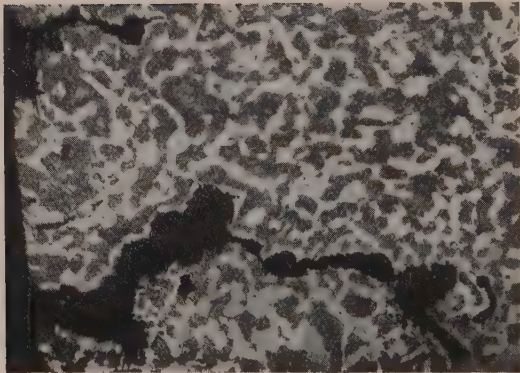


FIG. 13.

Transverse section through wall showing slag inclusion which appeared as a rake on the exterior surface.

ingots poured was common at some plants, and in some instances irregularity in manganese content was frequent. One of the large works eventually added the manganese to the ladle in the form of melted spiegel, and found that the results amply justified the extra cost. The variation in carbon content throughout each heat, in drillings taken from the same position in each ingot, was generally slight. The maximum variation at one plant, during a period of nine months, was 0.04 per cent. Aluminium, chromium, copper, and nickel never exceeded the content permitted. In deciding as to the acceptance or rejection of a heat on the high or low side in carbon or manganese the amount of both elements was considered. The following factors were derived from a large number of records of heats, and were useful in predicting whether a steel, when forged under suitable conditions, could be expected to pass the mechanical tests.

Basic open-hearth	(3C + Mn) 100	should be between 200 and 250.
Acid "	(4C + Mn) 100	" " 220 " 300.
Basic electric	(4C + Mn) 100	" " 225 " 310.
Acid "	(4C + Mn) 100	" " 220 " 290.

Identification was an important and difficult matter in connection with the inspection of steel, particularly with regard to the avoidance of the mixing of different heats.

Ingots.—Ingots having raised tops due to wildness of the metal (as apart from defects due to local dampness of mould) were rejected, and although some manufacturers raised controversy on the point, they were eventually convinced that such ingots contained cavities which were very unlikely to weld completely under the small amount of work applied in one punching operation. There were also differences of opinion between manufacturers and inspectors regarding the serviceability of ingots containing secondary piping. Numerous experiments were carried out, by forging shell from defective billets and sectioning, to endeavour to settle the point. While many such forgings appeared to be sound, some were certainly unsound, and in view of the unreliability of ingots showing secondary piping the safer policy of rejection was adopted. The photographs Figs. 7 and 8 (Plate XIX.) show secondary piping in the billet and after forging. Near the cavity in the base of the forging is a

fine vertical fissure connected with the bottom of the cavity. The splashy pouring of ingots gave trouble from time to time. Layers of metal, loosely adhering to the surface of the ingot, were formed in this way, and produced seams on the forged or rolled surface, causing the rejection of large numbers of machined shells. Segregation revealed as a central patch closer in texture than the remainder of the fracture, and reediness in the fracture, due to the presence of slag or piping, were found in the rolled bar. Trouble arose from time to time with surface defects and transverse cracks in ingots caused by the surface being held during contraction at locally worn parts of the mould, and ceased on the substitution of new moulds.

Forgings and Rolled Bar.—Mechanical tests were made on specimens cut from the forging or bar. In case of failure retests were permitted. After passing the mechanical test the forgings and bars were examined for surface defects and any necessary chipping was done. The ends of billets cut from bar were examined for piping and serious segregation effects. When abnormally irregular results were given by the mechanical tests of a batch the hardness of the forgings was determined by the Brinell method. A ball of 10 millimetres diameter and a load of 3000 kilogrammes were generally used. By this means the forgings were separated into batches for retesting and retreatment as might be required. In some cases the irregularity in mechanical properties was found to be due to lack of uniformity in heating before forging. In one instance the Brinell hardness varied from 179 to 223 in forgings of the same chemical composition. The range of Brinell hardness of steel which would give the required mechanical tests was 183 to 234. The forging was prepared for Brinell testing by filing a flat to a depth of at least 0.06 inch in order to ensure the removal of the decarburised outer surface. Forgings or machined shell which had lost their identification at any stage were generally tested and re-batched; the Brinell test was also extensively used in England for the individual testing of unidentifiable and wrongly marked forgings, and of forgings composing batches suspected of being abnormally soft. By this means many thousands of good shells, which would otherwise have been scrapped, were safely passed into service.

After the mechanical test-pieces had been cut from the forgings selected the bases of the same forgings were sectioned by sawing

and fracturing through the central portion. This practice was introduced for the detection of loose "cones," but was additionally useful in revealing the effects of overheating during forging. The formation of "cones" in the bases of shell forgings has been investigated to some extent by several makers of shell. Experiments carried out in England by Mr. J. Waite, formerly connected with the Inspection Department at Sheffield, showed that when a shell was forged from a billet by means of a flat-ended punch, a cone of metal, the apex angle of which was roughly constant, was carried down on the end of the punch and left in the base of the forging. When the billet was sound there was no metallic discontinuity between the cone and the body of the forging, and the shape of the cone was only revealed by the macro-etching of an axial section. In a forging punched from an unsound billet, on the other hand, the cone formed was generally not welded to the surrounding metal and was irregular in shape. In the case of a number of finished shells a hammer blow on the centre of the base was sufficient to dislodge a complete cone. It was found that a punch having an end contour similar to that of the cone formation in a sound forging completely avoided cone formation. A typical example of a loose cone, discovered as the result of the bulging of the base plate under the hydraulic test, is shown in Fig. 9 (Plate XX.). The defective region, including the metal of the cone, was exceptionally badly segregated. The photomicrograph, Fig. 10 (Plate XX.), taken near the line of separation, shows an area of phosphide eutectic.

Machined Shells.—Rokes and ghost-lines were the most prevalent defects in shells and rolled bars. Rokes were of varying lengths, showing on the surface of the shell as dark longitudinal lines, generally consisting of oxidised fissures surrounded by decarburised material, and formed as the result of the bursting of subcutaneous blowholes during reheating and forging. It was found by examination of numerous sections of roky shell that it was not possible to estimate the extent of a roke by its appearance on the surface. The filing of a groove across the roke gives some local indication as to its depth, but there is no certainty that the deepest region is being tested. In many cases rokes which appeared to be of the ordinary type were found to consist of slag inclusions such as that shown in Fig. 13 (Plate XXII.). The decarburised material in the neighbourhood of the inner

extremity of a roke showed, in some instances, as a ghost-line when machining had been only just sufficient to remove the roke proper.

Ghost-lines of the ferrite type containing central inclusions were fairly common in shell steel, but were generally of small extent. More pronounced and broader ghosts were found in some batches of basic steel bar. Sulphur prints showed intense local segregation of sulphur in elliptical patches at varying distances from the exterior surface, pointing to blowhole segregation as their origin. In the micro-examination of a number of such specimens the sulphide inclusions in the elliptical areas were in places connected by fine ramified black markings which suggested that complete welding had not been secured by the rolling operations.

Slag inclusions were of fairly frequent occurrence. The examination of several examples led to the conclusion that the majority of such defects were not connected with piping, but were due to the accidental admission of slag, solid or liquid, to the mould during casting, since the inclusions, sometimes of considerable magnitude, were found in all parts of the billet or shell.

Hydraulic Testing.—The hydraulic test for shells was devised in order to enable a proportion of shells which would otherwise have been rejected for the presence of external defects to be accepted for service. The test was applied to each shell affected, in specially designed machines. The pressure specified for 4·5-inch shell was 5 tons and for 6-inch shell 6·3 tons per square inch. In all 57,551 shell were tested, of which 44,970 were 6-inch and 12,551 4·5-inch. Details of the rejections are given below :

Shell burst under pressure	3
Leaky base	44
Expanded body	690
Expanded bases	532
Expanded body and base	27
Total	1296

The average elastic expansion of the walls of a 6-inch shell was 0·008 inch, and after release of pressure there was usually a slight lag in the recovery. It is notable that at least half the shells which leaked through the base did not show any visual

indication of unsoundness in that region. The effect of a leak through the base was to bulge or displace the base plate. Bulged base plates were, however, found to be due in some instances to slight yielding of the shell base. About 80 per cent. of the shells rejected on hydraulic testing contained marked rokes, and as a general rule a shell containing extensive rokes would fail in the subsequent ring gauging. There were, however, a number of shells specially tested as containing very bad defects, which did not expand sufficiently to cause rejection.

One of the shells which burst under the test is shown in Fig. 11 (Plate XXI.). The fracture, exposed by sawing through the wall opposite to the burst, showed an extensive defect running the whole length of the shell. The report of the inspector on the bursting of this shell stated: "No particular note was made of this shell before testing: after being submitted to the pressure of 6.3 tons the shell was taken out of the machine, emptied of water, and ring gauged. The ring gauge failed to pass over the shell, and it was noticed that on the body of the shell, about where the parallel commences, there was a slight crack of length about $\frac{1}{4}$ inch. The only strange action that can be noted is that in this shell, when released from all pressure, the crack developed to a length of 6 inches in the space of five minutes, and that a $\frac{3}{1000}$ -inch feeler could be inserted in the crack to a depth of $\frac{1}{4}$ inch. The shell was then again placed in the machine and resisted the pressure of 6.3 tons for the space of five seconds without showing any leak, then burst." On examination the failure was found to be due to the presence of a group of seams of slag, originally of a highly oxidising nature, which had been trapped on solidification of the ingot in casting. The largest seam was that forming the actual fracture surface. The small rokes, which were the only evidence of the shell being faulty before testing, were found to be outlying portions of the main defect, exposed by the machining of the shell. The defect had no connection with piping, and the shell generally, apart from the defect, was sound and free from segregation. Fig. 12 (Plate XXII.) is a photomicrograph of a section through the slag seam and surrounding decarbonised material, and Fig. 13 (Plate XXII.) shows a transverse section through a slag inclusion which showed as a roke on the exterior surface.

Iron and Steel Institute.

ON THE CONSTITUTION OF CHROMIUM
STEELS.¹

By THOMAS F. RUSSELL (SHEFFIELD).

INTRODUCTION.

THE subject-matter of this report is a somewhat ambitious one, and it may be many years before all the problems in connection with chromium steels—particularly when in the metastable condition—are elucidated.

Probably the surest and quickest method of doing this is, in the first place, to build up that corner of the iron-chromium and carbon thermal equilibrium model which represents chromium steels in the stable state.

This involves an enormous amount of spade-work to determine the various points, examine microstructures, &c., and has been done as far as the author's series of steels would allow. It is believed that sufficient work has been done to show the general type of model, but many more steels will have to be examined before certain lines in the diagram can be definitely fixed.

Fig. 1 is drawn to scale and shows that portion of the iron-chromium and carbon field examined in this report. The carbon reaches 1 per cent. and the chromium up to 12 per cent., with an occasional odd sample outside these limits. Attention is directed to this diagram at this early stage to point out that if there be a eutectoid plane over this relatively small shaded area, this plane will probably be only very slightly inclined to the basal plane, and therefore particular care has been taken with the determination of the carbon change point.

In a work of this nature it is essential that the apparatus and methods employed should be open to the fullest criticism, and no apology is made for giving detailed particulars of each experiment.

¹ *Carnegie Research Memoir*, received March 10, 1921.

It is, of course, inevitable that some of the work has been already done, and several well-established facts are not recorded,

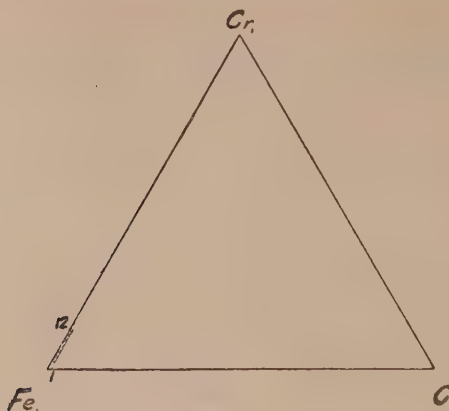


FIG. 1.

except when there is something of special interest to be pointed out.

In view of the excellent history of chromium steels recently published by Professor Edwards,⁽³⁾ it is not considered necessary to write one here.

SYNOPSIS OF THE REPORT.

INTRODUCTION.

PART I.—*Manufacture of the Steels.*

Analysis.

The effect of metallic chromium on furnace gases.

PART II.—*Thermal Data.*

Preliminary considerations.

Diffusion and stable equilibrium.

Details of apparatus.

Typical time-temperature, differential and inverse rate curves showing rate of cooling.

Table of results.

The Ac₂ point.

The Ar₁ point.

The Ac₁ point.

The effect of chromium with constant carbon.

PART III.—*The approximate Determination of the Solidus and Carbide Solubility Point.*

Hardness of quenched pieces.

Cracking zones.

Austenite retained by quenching.

PART IV.—*The Analysis of Carbides and Residues.*

Theoretical considerations.

Methods of preparing carbides and residues, and subsequent analysis.

Details of treatment and results.

PART V.—*The Electrical Resistance.*

Apparatus and oil bath.

Treatment of the bars.

Temperature coefficient.

Table and diagram of results.

PART VI.—*Conclusions, General Discussion, and Criticisms.*

General form of the thermal-equilibrium model.

Microscopic examination.

Distribution of the chromium as shown by resistivity and carbide tests.

Probable isothermal eutectoid lines.

Guillet's classification.

The importance of diffusion-analogy to the brasses. Oberhoffer's eutectic line.

Acknowledgments.

References.

PART I.

MANUFACTURE OF THE STEELS.

The author is indebted to Messrs. Peter Stubs, Ltd., Rotherham, who kindly undertook the manufacture of these research steels. They were made from best Swedish iron, "S" brand, ferro-chrome, and either metallic chromium or charcoal, by the usual Sheffield "white clay" crucible process. A quarter of an ounce of aluminium was added just before teeming into 3-inch ingots. The ingots were stripped as hot as possible and allowed to cool overnight in the ashes under the gob fire, but this did not prevent several of them from being too hard to saw. All the ingots poured well, except A, which rose slightly in the mould.

The ingots were reheated and rolled down to 1-inch rounds, the first few passes being very light. The ingots, except A, rolled perfectly.

Table I. gives the analysis of these steels, and shows them to be a very pure series of iron-chromium alloys, but the variation in carbon and chromium, which was intended to be from 0.25 to 1 per cent. and from 1.50 to 12 per cent., is not as good as the author would have liked.

Accordingly five more steels were made at the Applied Science Department of Sheffield University, by the courtesy of Professor

TABLE I.—*Chemical Composition of Steels.*

Mark.	C.	Cr.	Si.	S.	P.	Mn.
<i>Steels made at Messrs. Peter Stubs, Ltd.</i>						
A	0.25	1.56	0.049	0.060	0.015	0.10
B	0.26	3.05	0.035	0.068	0.015	0.10
C	0.47	6.08	0.051	0.084	0.017	0.11
D	0.59	8.38	0.086	0.093	0.017	0.10
E	0.64	12.2	0.150	0.098	0.014	0.05
F	0.39	1.49	0.043	0.062	0.017	0.10
G	0.46	3.02	0.066	0.076	0.018	0.10
H	0.78	6.12	0.088	0.057	0.017	0.10
I	0.77	9.03	0.092	0.100	0.017	0.10
J	0.79	12.10	0.169	0.059	0.014	0.10
K	0.65	1.49	0.073	0.041	0.020	0.12
L	0.65	3.20	0.073	0.041	0.015	0.10
M	0.66	6.22	0.056	0.079	0.012	0.10
N	0.87	8.85	0.103	0.085	0.014	0.10
P	0.82	1.54	0.050	0.032	0.011	0.12
Q	0.91	2.96	0.047	0.044	0.018	0.07
R	0.86	5.70	0.069	0.059	0.026	0.12
S	0.84	8.59	0.116	0.056	0.015	0.07
T	1.08	11.36	0.169	0.104	0.018	0.08
<i>Steels made at the Department of Applied Science, Sheffield University.</i>						
1686	0.50	13.22	0.094	0.057	0.010	0.05
1687	0.65	13.34	0.060	0.076	0.006	0.06
1688	0.44	9.00	0.066	0.058	0.008	0.04
1689	0.50	8.21	0.131	0.067	0.007	0.05
1690	0.44	5.46	0.051	0.069	0.013	0.05
<i>Other Steels mentioned in the Report—Professors Arnold and Reid's Series.</i>						
1091	0.85	10.15	...	...	...	...
1092	0.88	15.02	...	...	...	...
1148	0.85	19.46	...	...	...	...

TABLE II.

No.	Made for		Analysis.		Weights Used.					
	C.	Cr.	C.	Cr.	Mild Steel.		Ferro-Chrome.		Metallic Chromium.	
					lbs.	ozs.	lbs.	ozs.	lbs.	ozs.
1690	0.25	6.0	0.44	5.46	46	2	2	2	1	11
1688	0.20	9.0	0.44	9.00	45	14	1	8	3	10
1686	0.20	12.0	0.50	13.20	42	6	1	8	6	2
1689	0.40	9.0	0.50	8.21	44	2	3	12	2	2
1687	0.40	12.0	0.65	13.34	41	8	3	12	4	12

C. H. Desch, D.Sc., and under the supervision of Mr. F. K. Knowles, M.Met.

This series is of more than usual interest in view of the fact that very careful records are kept of everything relating to the manufacture of experimental casts.

The materials used were :

Steel	C. 0·08	Si. trace	S. 0·030	P. 0·013	Mn. 0·20.
Ferro-chrome . . .	C. 4·36	Si. 0·234	S. 0·15	Cr. 62·2.	
Metallic chromium	C. 0·14	Si. 0·240	S. 0·09	Fe. 0·70	Al. 0·70
					Cr. (by analysis) 98·8

Table II. shows the weights of each used, the calculated percentage, and the actual percentage obtained.

Once again an attempt to make a low carbon chromium alloy had failed, and Mr. Knowles, who has had a very wide experience in the manufacture of special alloys by crucible process, was invited by the author to comment on these results.

The following is the note furnished to the author by Mr. Knowles :

“ The melting of mixtures of materials, of known analyses, by the coke-fired crucible process using the Sheffield ‘ white clay ’ crucibles, to produce steels of specified carbon and chromium percentages, offers little difficulty provided that ferro-chromium is the source of the chromium required. When, however, the chromium is added in the form of metallic chromium there is a loss of chromium which increases in a progressive manner as the chromium percentage required in the ingot increases, and often this loss of chromium (from metallic chromium) is accompanied by a gain in carbon.

“ That there is no appreciable loss of chromium from ferro-chrome is confirmed by a reference to the chrome steels of McWilliam and Barnes,¹ and the first five steels of Arnold and Read.² In the remaining two steels of Arnold and Read, 14·04 per cent. and 19 per cent. of chromium added in the form of metallic chrome, out of a total addition of 20 per cent. and 25 per cent., show losses of 24 per cent. and 21·5 per cent. from the chromium metal, or on the total chromium added 14 per cent. and 14·7 per cent.

¹ *Journal of the Iron and Steel Institute*, 1910, No. I.

² *Ibid.*, 1911, No. I.

“ In the latter two cases there is no gain in carbon but the steels were of nearly 0·9 per cent. carbon content. Also the loss of chromium and gain of carbon when metallic chromium is used in the coke crucible process have caused considerable difficulties in the production of stainless steels by small firms with no laboratory.

“ The five steels melted in the coke crucible furnace of the University of Sheffield for your research form an interesting corroboration :

No.	Carbon.		Chromium.		Chromium.	
	Added.	Found.	Added.	Found.	From Ferro.	From Cr. Metal.
1690	0·26	0·44	6·06	5·46	2·64	3·42
1688	0·21	0·44	9·01	9·00	1·84	7·17
1686	0·21	0·50	13·95	13·22	1·84	12·11
1689	0·40	0·50	8·86	8·21	4·66	4·20
1687	0·40	0·65	14·05	13·34	4·66	9·39

“ These data, whilst not sufficient to prove, suggest that there may be a relation between the carbon gained and the chromium added as metallic chromium in low carbon steels. Plotting for the first three and then last two of these steels, with chromium added as metallic chromium, as ordinates and carbon gained as abscissæ, the three points form a straight line and the last two joined, a line nearly parallel with the first.

“ The suggestion that the carbon is taken from the coke dust in the crucible mixture is not satisfactory, as no carbon is gained when ferro-chrome alone is used, and further there is only about 6·6 per cent. of coke dust in the crucible mixture.

“ It is just possible the chromium added in the metallic state may act to some extent like aluminium¹ by taking oxygen from carbon-monoxide, thus liberating carbon. When steels such as those under discussion are practically ready for teeming, a crust forms on the surface of the melt, and the longer the steel is left in the melting hole the thicker this crust becomes. Aluminium and vanadium when present act in a similar manner.

¹ Arnold and Knowles, *Journal of the Iron and Steel Institute*, 1897, No. I.

“ If it be proved that the metallic chromium used contains appreciable amounts of aluminium, the increase in carbon is readily explained. The parcel used for these five steels is reported as containing 0·7 per cent. aluminium, which only accounts for a gain of 0·08 per cent. carbon in steel No. 1686, to which the largest addition of metallic chromium was made.”

The suggestion that metallic chromium produces the same effect as both aluminium and, to a less extent, vanadium, in reducing carbon from the furnace gases, is a very interesting one, and is supported by the results of an examination of the steels made by Messrs. Peter Stubs, Ltd. The gain in carbon is roughly proportional to the weight of metallic chromium.

Additional confirmation of this is obtained from several makers of stainless steel whose opinion has been consulted. The smaller firms, who successfully make chromium steel in crucibles, calculate their mixtures to give about 0·15 per cent. carbon and contain about 0·35 per cent. in the finished steel. The larger firms use an electric furnace.

PART II.

THERMAL DATA.

A study of the published recalescence data of chromium steels led the author to expect very little light to be thrown on their constitution from this source. Nor is this surprising, for whereas heating and cooling curves of a series of alloys of widely different composition give very valuable information, one can hardly expect much difference in these curves for alloys existing in the very small area of the field shown in Fig. 1. Nevertheless an exact knowledge of the temperatures at which certain changes take place is as indispensable as the chemical analysis, and it was decided to make a thorough investigation into the thermal changes.

That these temperatures must be accurate is obvious, but it is of even more importance to know that the temperatures are strictly comparable, as any differences are likely to be very small, and unless one can say with positive certainty that a change in an alloy takes place at a higher or lower temperature than a

similar change in another alloy, the results would lose much of their value. The author is assuming that the theoretical change point of a eutectoid is dependent only on its composition, and any slight change in composition is accompanied by a change in the decomposition temperature.

It is also necessary that the temperature of the changes which are taking place in the small sample under treatment should be the temperature at which these changes take place when the steel attains stable equilibrium.

Both these essentials are real difficulties in the case of chromium steels, for it is now generally known, thanks to the pioneer work of Edwards ^(1, 2, 3) and his co-workers, that the temperature of the carbon change point on cooling, and the quantity of heat evolved, are both lowered by raising the initial temperature, or by increasing the rate of cooling.

The author believes he has satisfactorily overcome both these difficulties by making use of those temperatures which he has found do not materially alter for wide variations of the conditions; for most of the steels the heating curves are used, but for a few, chiefly the hypo-eutectoid ones, the cooling curves are compared.

Another important point so often overlooked in the case of ferrous alloys, is that the constituents should be as perfectly diffused as possible. The author knows of no investigation on steels where it is definitely stated that this precaution was taken.

Its importance was forced home in this work, and attention may be at once directed to Micrograph No. 1, Plate XXIII., which shows a typical chromium steel in the "as rolled" condition, and then made pearlitic by suitably slow cooling. It has been etched with Dr. Stead's copper reagent, and shows coring due to the differences in concentration of chromium and carbon.

A steel G, with 0.46 per cent. carbon and 3.02 per cent. chromium, was heated to 830° C., which had been previously found to be high enough to get all the carbides in solution, and was very slowly cooled to 770° C. and quenched in water.

Micrograph No. 2, Plate XXIII., shows the structure after etching with copper reagent. The cored structure of the martensitic background is still present and the change to pearlite is just commencing, in most cases in interdendritic fillings.

Micrograph No. 3, $\times 500$, leaves no doubt that this is pearlite.

The pearlite change would take place over a range of temperature the size of which would depend on the differences of concentration of chromium and carbon in the spines and inter-fillings of the original dendrite.

This steel is known to be hypo-eutectoid, and therefore ferrite or chromiferous ferrite ought to be the first to separate out. A study of Figs. 2 and 3, which show heating and cooling curves of steels G and B in the diffused and undiffused condition, will confirm this. It is of particular interest to note that the differential cooling curves of the diffused steels show that a change is beginning to take place at 772° C. and 808° C. respectively. This is the falling out of solution of chromiferous ferrite and may easily have been overlooked on the inverse-rate curve.

With the undiffused bar neither type of curve gives any indication whatever of this action.

These curves lose much of their value by being plotted on so small a scale, but a study of the original curves submitted with this report will show that for research purposes it is imperative that the low chromium steels especially should be perfectly diffused.

Many of the high chromium steels have not been investigated in the diffused state owing to the lack of time, and also the practical difficulties of getting them in this condition. It is, however, fortunate, from this point of view, that diffusion is of minor importance in the high carbon and chromium steels. It will be seen later that beyond a certain percentage of chromium, additions of that element have only a very slight effect on the temperature of the change point on heating, so that the range over which the carbon change point takes place, due to the difference in concentration of the chromium, is only a very narrow one and negligible.

It was found that for low chromium steels, heating from five to eight hours at 1200° C. was sufficient to diffuse the constituents, and the question arose as to whether this long heating would alter the nature of the compounds present. Such changes take place, for example, in high carbon steels and silicon steels.

An examination of the recalescence curves and the micro-structure before and after diffusion gave no evidence of any such change having taken place.

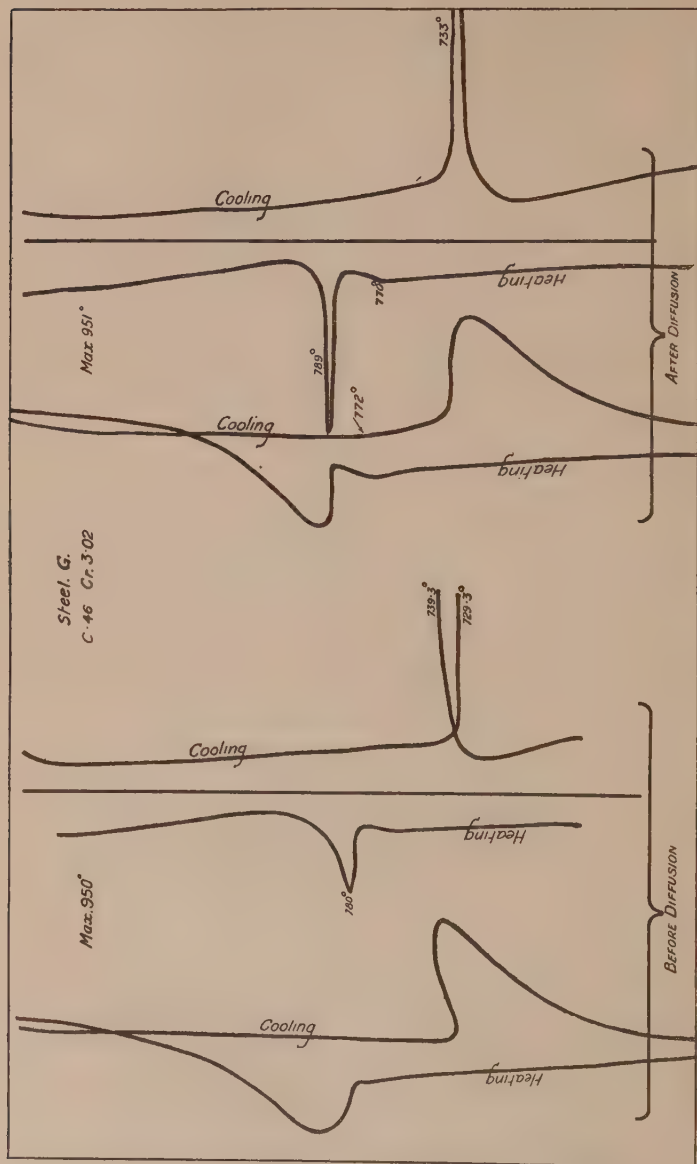


FIG. 2.—Showing the Effect of Diffusion on the Recalescence Curves of Steel "G."

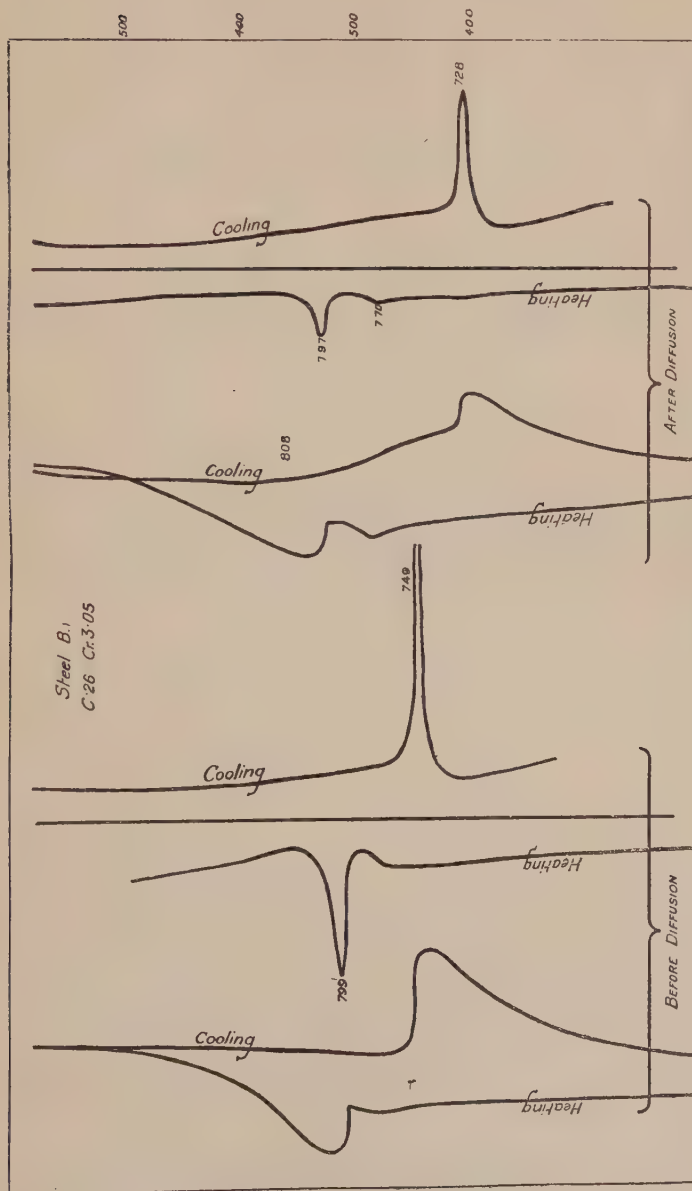


FIG. 3.—Showing the Effect of Diffusion on the Recalescence Curves of Steel "B."

In this recalescence work it was decided to plot both the inverse rate and differential heating and cooling curves from data obtained from the same experiment. At first sight this may appear an unnecessary amount of work, but the results have fully justified the extra trouble taken.

The differential curve often showed a feature which could not be detected on the inverse rate curve and *vice versa*.

DETAILS OF THE PRACTICAL WORK.

The recalescence pieces were all taken from the same relative position in the ingot, viz. after cutting off about 6 inches of the

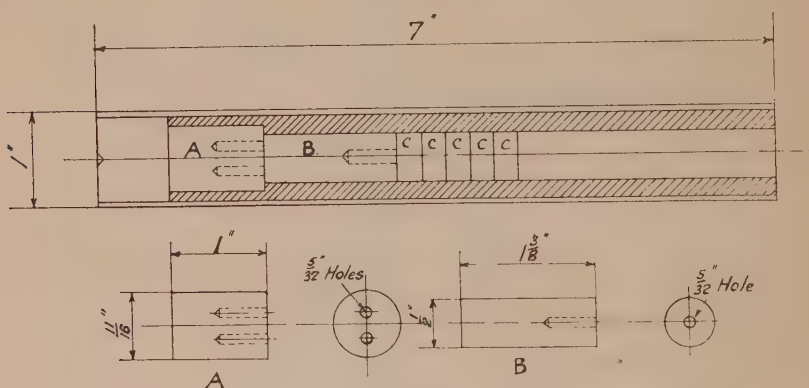


FIG. 4.

rod corresponding with the bottom of the ingot the next 7 inches was turned as shown in Fig. 4. The outer layer to $\frac{1}{16}$ -inch radius was discarded and the turnings from the shaded portions were used for analysis. A was used for the differential and the inverse rate curves given in the report. In some cases this piece was then thoroughly diffused; in other cases a fresh portion of the bar was diffused before cutting out the recalescence piece.

B was used for taking inverse rate curves only, when it was desired to study the effect of initial temperature and the rate of cooling.

C are microsections for heat treatment and microscopical examination, particularly for the determination of the Acm

point and solidus. For some of the steels these pieces were replaced by cubes as explained later.

The neutral piece was made of a nickel-iron alloy containing 42.5 per cent. nickel and 0.11 per cent. carbon. No thermal disturbance whatever was found on heating and cooling over the studied range.

The arrangement of the pieces in the furnace is fully explained in Fig. 5. The furnace was nichrome wound.

The differential couple was platinum platinum-rhodium; this was cut in two and connected to the terminals T as shown, and used with a suspended coil mirror galvanometer, which had a millimetre scale placed two metres away from it.

To determine the temperature of the piece, a platinum platinum-rhodium couple in conjunction with a deflection potentiometer, made by Robert W. Paul, was used.

The new couple was calibrated with a fixed points tin, lead, zinc, aluminium, sodium chloride, silver and copper, and the relation between the generated E.M.F. and the temperature was very accurately expressed by $\log. E. = 1.240, \log. T. + 3.3485$.

For the first few curves the times were recorded on a chronograph, but this was soon abandoned, as it was found that equally satisfactory results were obtained by counting the seconds ticked out by an electric pendulum.

One scale was placed close above the other, and for most of the curves the spots of light were quite steady.

The number of seconds for the light to move 5 millimetres on the temperature scale was noted, and also the corresponding reading of the differential scale.

Five millimetres represented 2.8°C. , but the rate of heating and cooling was slow enough to allow readings to be taken more frequently, that is, every 1 or 2 millimetres when approaching the recalescence range, and it is considered that the figures given represent the true value for these steels to 1°C. under the conditions of the experiment.

The rate of heating varied somewhat for each experiment, but the cooling rate was practically constant. Fig. 6 shows a typical cooling curve, and the time required to fall through 1°C. at different temperatures has been calculated.

The original scheme was to obtain two complete sets of

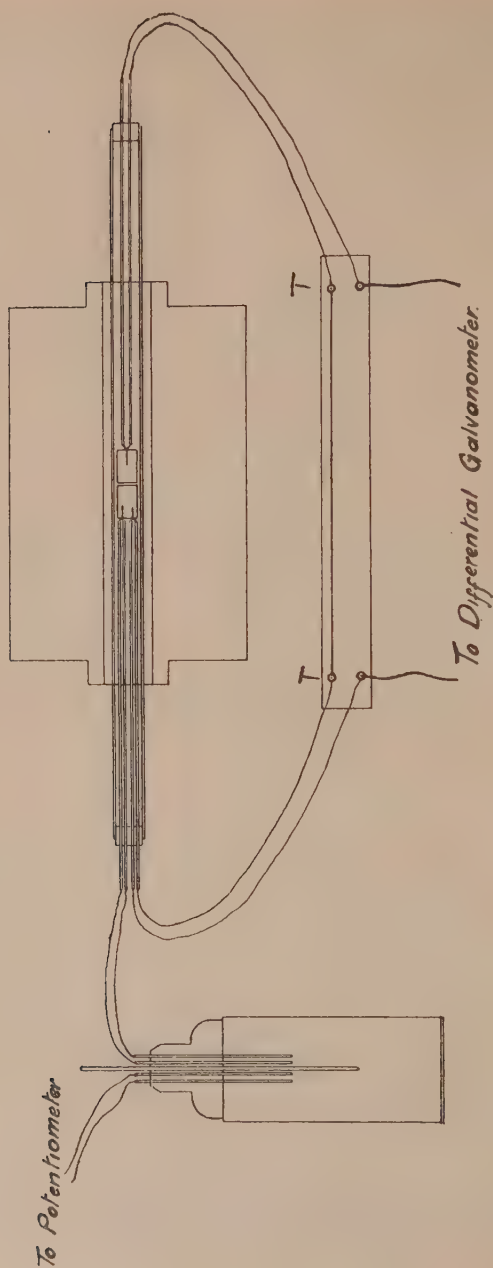


FIG. 5.

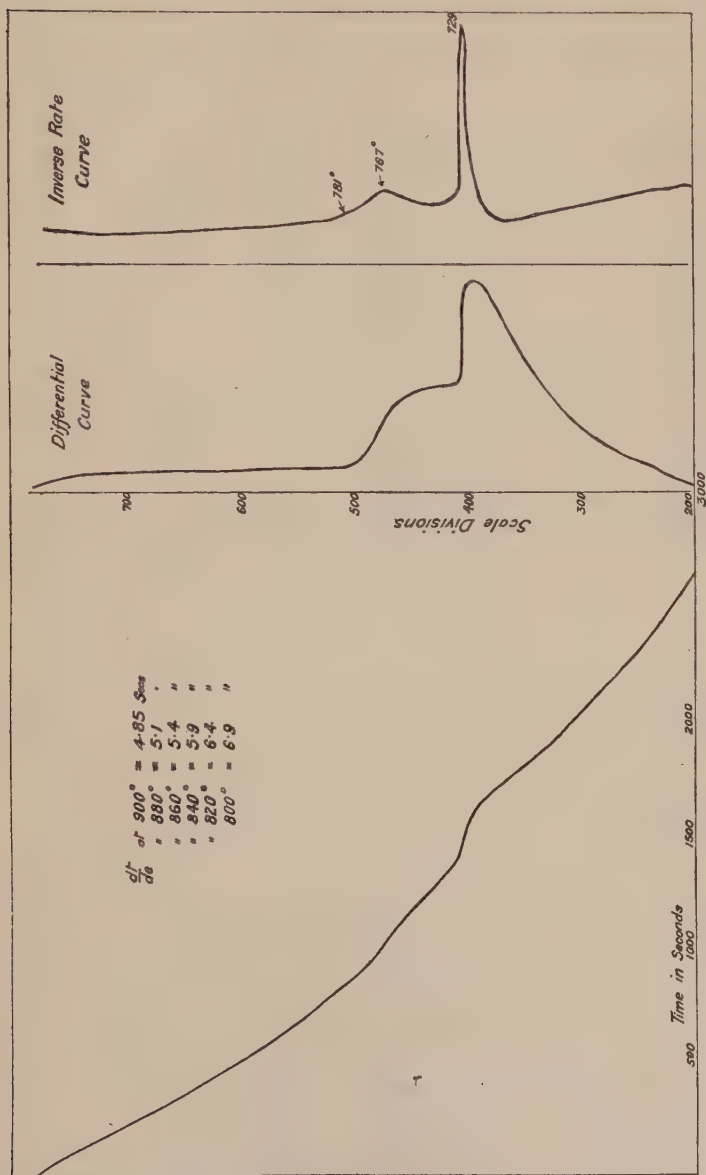


Fig. 6.—Typical Cooling Curves (Steel "A") showing Rate of Cooling.

curves; a set including inverse rate and differential heating and cooling.

The first set was from 200 div. = 513°C. to 800 div. = 942°C. , then back to 200 div. This was particularly tedious work, requiring one and a quarter hours concentrated attention and counting, but it was felt that only by continuing the curves for some distance on both sides of the range would one be able to compute with any accuracy the relative quantities of heat evolved. Although the author has nothing striking to point out in this connection, the figures are now available.

The second set was from 300 div. = 669°C. to as little as possible above the carbon change point, maintain that temperature until equilibrium between the test-piece and the neutral was attained, and then to cool. According to Professor Edwards⁽³⁾ this should represent the highest possible temperature at which the carbide change can take place.

The results are given in Table III.; where "overheating" and "undercooling" occurred both the highest and lowest temperatures attained are recorded. All the original curves are submitted with the report, and the author has picked out and replotted only those curves which are essential for the text.

The Ac2 Point.—Moore⁽⁴⁾ was the first to point out that the addition of chromium progressively raised the Ac1 point until it was above the Ac2 point. The present work has thoroughly confirmed this, and also his statement that if the Ac1 is not exceeded Ar2 occurs at the same temperature as Ac2.

The curves here presented have brought out another very interesting feature which, as far as the author knows, has not been mentioned previously. In the first place a very careful study of the range, by altering the rate of heating, and by opening the scale of the potentiometer, has left the author quite undecided as to whether there is, or is not, an actual absorption of heat at this point. If there is an absorption it is only a very minute one. In every case where the Ac1 point is above the Ac2 point the differential curves show an abrupt change in direction, and the inverse rate curves show a quicker rate of heating above the Ac2 point than below it. This is clearly seen in Figs. 7, 8, and 9. The only logical conclusion is that at the Ac2 point there is an abrupt change in the diffusivity of the alloy. Diffusivity is a property

TABLE III.—*Recalescence Data.*

Mark.	O.	Cr.	Heating.		Highest Temperature Attained.	Cooling.	
			Ac1.	Ac2.		Ar2.	Ar1.
A	0.25	1.56	com. 756	max. 770	942	com. 781, max. 767	729
B	0.26	3.05	756	770	808	„ 781 „ 767	729
			797	770	947	(?)	728
			797	770	843	approx. 770	734
C	0.47	6.08	802	770	949.5		740.9-747.6
			804.5	770	819		770
D	0.59	8.38	812.1	770	943		756.3-760.2
			811.6	770	826		764.1-767.9
E	0.64	12.2	818.1	767	941		746.5-749.3
			819.1	769	835		756.3-761.8
F	0.39	1.49	771		937	com. 753, max. 744.8	730.4
			772.2		813	„ 761 „ 744.8	728.5
G	0.46	3.02	789.4	770	951		733.4
			788.3	770	817		742.1
H	0.78	6.12	800.8	770	941		746.5-752
			800.2	770	813		764.1
I	0.77	9.03	812.1	770	943		756-761.3
			812.1	770	821		768-771.2
J	0.79	12.1	815.1	767	941		755.3-757.5
			815.4	767	826		763.3-767.3
K	0.65	1.49	759		945		719.3-729
			759		777		737.1
L	0.65	3.20	781.2	770	790.4		753.3
M	0.66	6.22	810	768	942		751.4-756.5
			809	769	848		769-772.5
N	0.87	8.85	813.2	770	937.4		765.5-773.4
			...	770	836.5		770-776.2
P	0.82	1.54	758.5		952		709.3-711
			758.5		792		727
Q	0.91	2.96	770		942		725.4-732.7
			770		821		741-742.7
R	0.86	5.70	795.1	770	939		743.9-748.9
			793.8	770	805		769
S	0.84	8.59	...		941		755.8-760.2
			811	771	845		756.8-760
T	1.08	11.36	814	767.4	940.5		761.6-765.3
			813.7	770	840		767.9-771.8
1686	0.50	13.22	819.7	745	953		711.5
			819.7	745	841		731
1687	0.65	13.34	818.1-816	750.3	948		725
			...	753	830		740
1688	0.44	9.0	812.7-808.9	764	950		729.3
			812.7-808.9	764	831		751.4
1689	0.50	8.21	814.3-811	767.4	950		737.1
			812.7-816.5	...	844		752.2-754.5
1690	0.44	5.46	809-807	770	947		727.1-731.5
			809.4-807.3	772	828		753.1
1091	0.85	10.15	818.7	774	952		759.1-769.8
			823.4	772	834		780.6
1092	0.88	15.02	823.5-822	756	945		742
			...	...	838		764

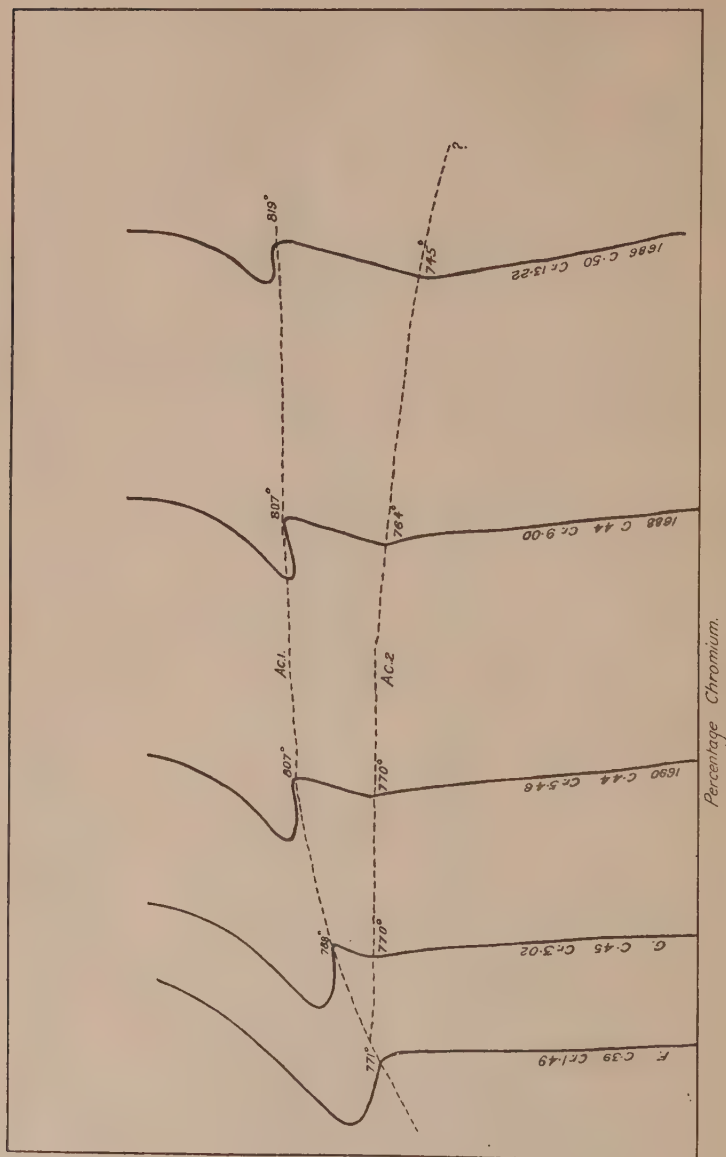


FIG. 7.—Showing the Effect of Chromium on the Carbon Change Point on Heating. Differential Curves. Carbon, 0.40 to 0.50 per cent.

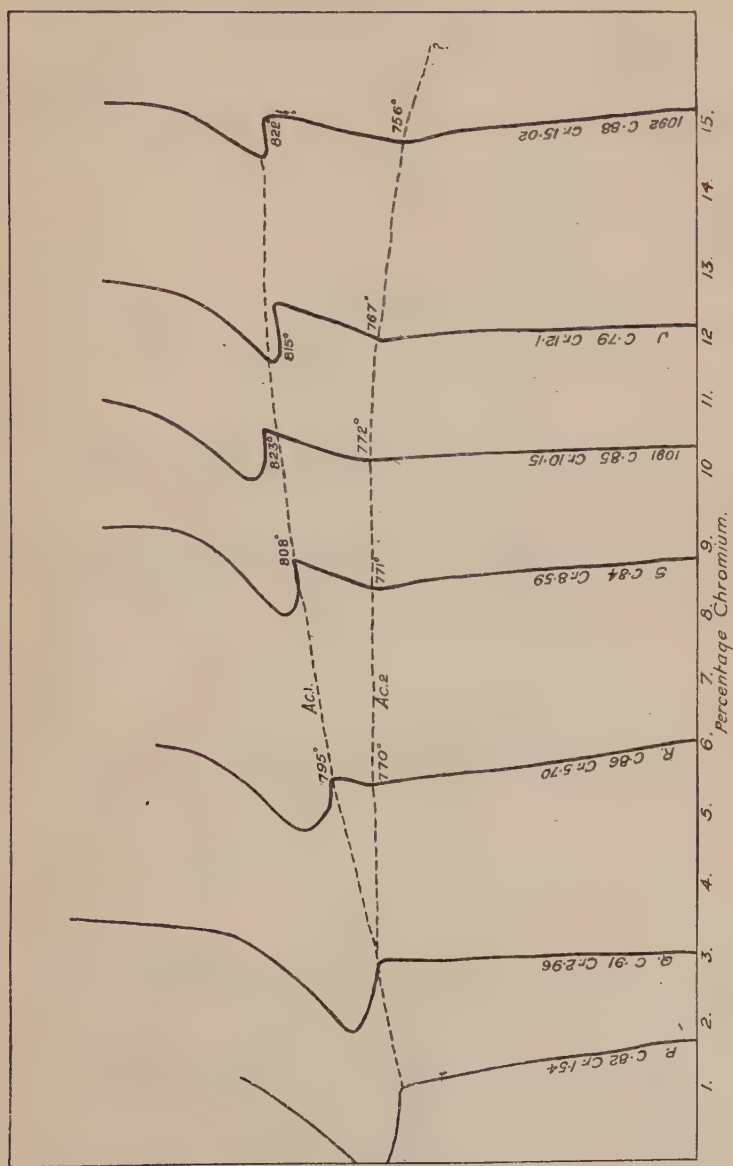


FIG. 8.—Showing the Effect of Chromium on the Carbon Change Point on Heating. Differential Curves. Carbon, 0.80 to 0.90 per cent.

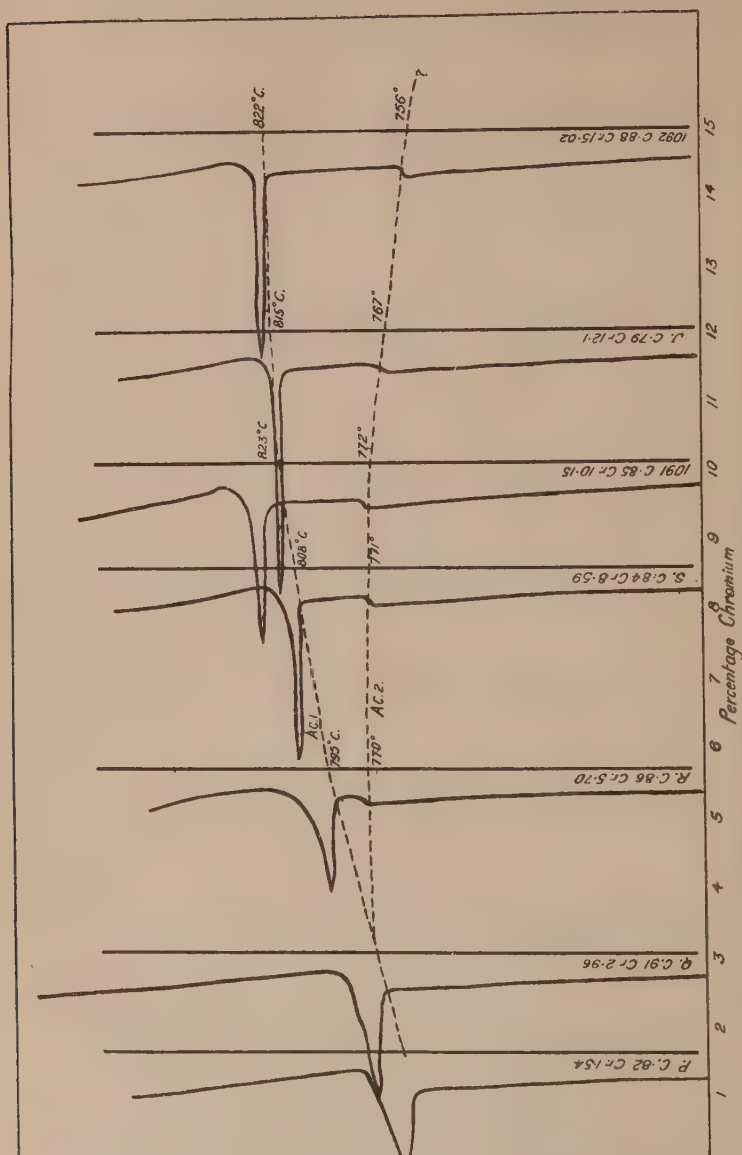


Fig. 9.—Showing the Effect of Chromium on the Carbon Change Point on Heating. Inverse Rate Curves. Carbon, 0.80 to 0.90 per cent.

that depends on both the thermal conductivity and the specific heat. As it has been proved conclusively that pure iron has a lower specific heat above the Ac2 point than below it, it may be accepted that these features of the curves are due to an alteration in the specific heat alone. Nevertheless, the possibility of

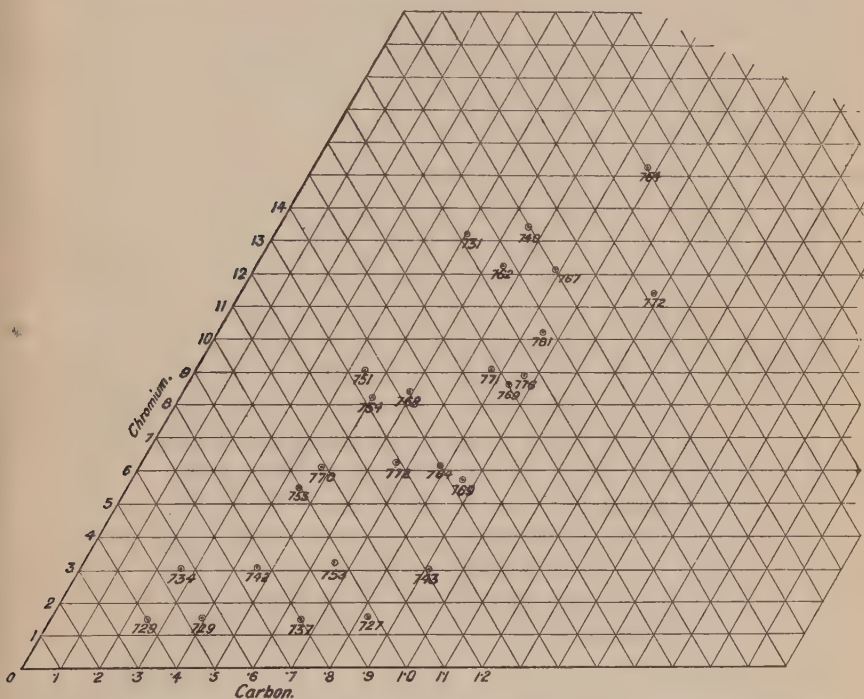


FIG. 10.—Showing Carbon Change Point on Cooling from Low Initial Temperature.

their being due to a change in the thermal conductivity should not be lost sight of.

For most steels the Ac2 point is at 770° C., but in Figs. 7 and 8 it can be seen that as the chromium increases there is a tendency for the point to be lower. A steel with 0.85 per cent. carbon and 23.7 per cent. chromium had the point at 700° C.

The Carbon Change Point on Cooling.—The fact that the carbon change points do exist—between 700 and 770—in all these steels is in itself of the utmost importance, for it at once renders Guillet's

classification of chromium steels untenable. This question will be discussed later.

In Fig. 10 the Ar points obtained by heating to just above the Ac points and slowly cooling are shown plotted on triangular co-ordinates, and the author believes that any attempt to draw satisfactory isothermal lines, which can be explained, will fail. Similar attempts for a high maximum also fail.

It may now be asked: "Does the change point under these conditions represent the highest possible temperature at which the carbon change can take place?"

To test this, a piece of steel I, with 0.77 per cent. carbon and 9.03 per cent. chromium, 2 inches long, was cut from the 1-inch round and a hole drilled for the insertion of a thermocouple. It was then embedded in lime in a box and heated to just over the recalescence point and cooled as slowly as possible. The thermocouple was connected to a Cambridge Scientific Instrument Co.'s thread recorder. Inserted between the cold junction and the recorder was a two-way switch, and when it was seen on the chart that the steel was recalescing, the current from the couple was switched over to the potentiometer (which had been adjusted for these conditions), and the temperature taken.

This method was more accurate than calibrating the recorder. The results obtained are given in Table IV. There can be little

TABLE IV.—Steel "I." Ac1 point, 812°.

	Initial Temperature.		Ar on Cooling.
1	943	Cooling rate as in Fig. 6	756-761.3
2	820	" " " "	768-771.2
3	941	" " slower than 1 and 2	771-778
4	920	" " " " 3	771-781
5	820	" " as in 4	780-784.6

doubt that the temperatures would have come a little higher still if the cooling could have been made even slower.

The plan of heating to just above the Ar point and then cooling was found to be very treacherous for hypo-eutectoid steels, as curves for steel B in the diffused bar will show.

Initial temperatures of 814°C. and 831°C. gave maximum evolutions of heat at 783°C. and 767°C. respectively, whereas an initial temperature of 843°C. lowered the Ar point to 734°C.

The possible explanation is that 814°C. and 831°C. were not high enough to take all the excess ferrite into solution, so that the parts of undissolved ferrite would be the nuclei around which further deposition would start at once on cooling.

After very careful consideration, the author is of the opinion that as there are only slight differences in the theoretical temperature of the carbon change points, and as the practical method of determining these temperatures, by cooling, is so liable to error, and the temperatures are not comparable, any deductions from them must be quite unreliable.

The Carbon Change Point on Heating.—Quite a different story can be told of the Ac points. In the early part of this work it was noticed how constant the Ac1 point came time after time. In one very severe test the Ac1 point was determined on a recalescence piece of type B by heating very slowly. It was then determined by plunging the cold piece into a furnace already at 1000°C. The temperatures varied only by a fraction of a degree.

Confirmatory evidence of this was given by Edwards,⁽³⁾ who wrote : " The temperature of the carbon change on heating was found to be virtually constant for each particular steel, even when rates of heating were widely different, but when the heating was very slow there appeared to be a tendency for the transformation to commence at 2° to 3° lower than when the rate was somewhat rapid."

This is particularly true for those steels whose Ac1 point is above the Ac2 point.

Fig. 11 shows the Ac1 point plotted on triangular co-ordinates. There are also drawn some theoretical isothermal lines, but as these were deduced after the carbide analysis, and the resistivity measurements had been made, consideration of them will be left for the time being.

Fig. 7 shows the differential heating curves for a series of steels with 0.40 per cent. to 0.50 per cent carbon.

Fig. 8. A similar series with 0.80 per cent. to 0.90 per cent. carbon.

Fig. 9. The inverse rate heating curves for the same series as Fig. 8.

PART III.

THE APPROXIMATE DETERMINATION OF THE SOLIDUS AND THE CARBIDE SOLUBILITY POINT.

The solidus may be determined theoretically by finding the lowest point on the solidifying range on allowing the molten alloy to cool, but in Part VI. it is shown that the practical difficulties of this method would be almost insurmountable. In this work the alternate method was used. The steels were gradually heated to increasing temperatures and the point noted where incipient fusion or "burning" took place. It was very difficult indeed to decide in some cases whether the steel was burnt or not, but there was no doubt whatever about the points plotted on Fig. 12.

By the carbide solubility point is meant that temperature at which all the excess carbide goes into solid solution. Attempts were made to determine this temperature by continuing the heating and cooling curves up to the region of 1200°C. , substituting a platinum-wound furnace for the nichrome one, but as was almost to be expected at this high temperature both types of curve lost their smoothness and are not included in this report. The method of quenching from different temperatures and examining the microstructure was used.

A steel was carefully diffused by prolonged heating at 1200°C. and microsections cut. These were quenched every 50°C. up and examined. The result can only be described as a failure. Probably owing to the smallness of the sample of steel, the excess carbide was so finely divided that it was almost impossible to tell when it was all in solution. All the usual etching reagents were tried with the same unsatisfactory results.

When, however, similar experiments were tried with the "as rolled" or undiffused bar and Murakami's reagent used it was found that the excess carbide was always in the interfillings and the dendritic pattern faded away when all the carbide had gone. This probably represents a higher temperature than would be obtained from the diffused bar, but it is near enough for the purpose, for after all, the object of these determinations is not so much to find the exact contour of any surface, but rather to find where these surfaces meet. In other words, the object is to

determine the limits of solid solubility of chromium and carbon in gamma-iron, for as soon as these limits are exceeded, the ternary eutectic appears.

The first experiments with thin circular microsections led to some interesting observations being made on the cracking pro-

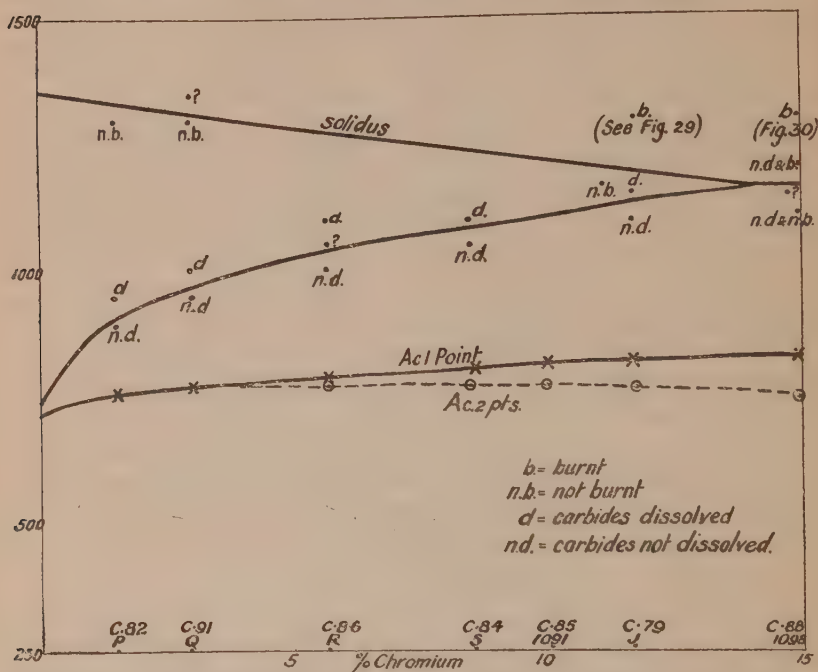


FIG. 12.—Rough Section through the FeCrC model with carbon 0.80 to 0.90 per cent.

perties of the steels, and also on the Brinell hardness of the quenched pieces, and although it was not apparent at this stage what relation there was between cracking properties and constitution it was thought that the results may have some commercial value. The experiments were therefore restarted, but this time small cubes instead of thin microsections were used. A series P, Q, R, S, J, with 0.80 to 0.90 per cent. carbon and 1.5 to 12 per cent. chromium was chosen, and cubes $\frac{1}{8}$ -inch sides were cut from the bar and holes made for the thermocouple. A piece of thin platinum wire was wrapped once round each cube, which was

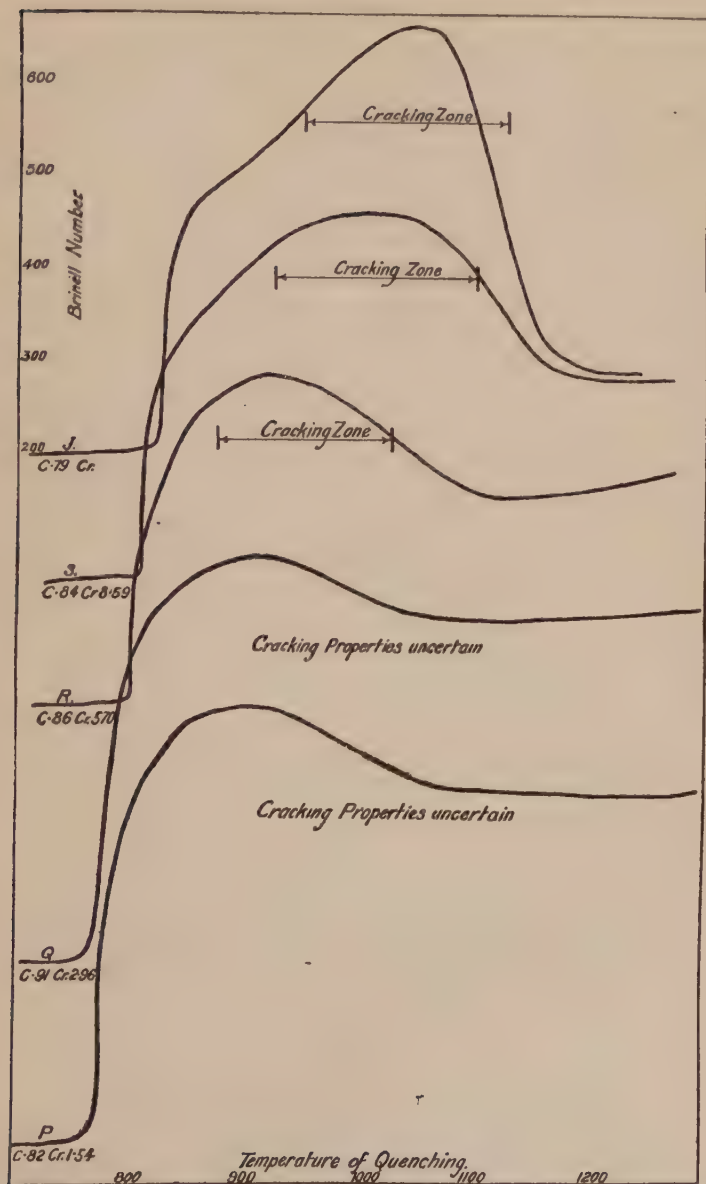


FIG. 13.

placed in a silica test tube and heated very slowly in a platinum-wound horizontal electric furnace. As soon as the desired temperature was reached the cubes were pulled out by means of the platinum wire directly into a bucket of cold water. After carefully grinding off the scaled surface, Brinell impressions were taken, and the face representing the transverse section of the bar was examined microscopically.

The quenching temperatures and the corresponding Brinell numbers are plotted in Fig. 13.

That high chromium steel may be made austenitic by quenching from a suitable high temperature is well known, and these curves fully confirm this. Steel J shows this most markedly, and also brings out very clearly the increase in the hardness due to the solution of the excess carbide. The latter effect may be traced to a diminishing extent as the chromium is lowered.

It was noticed that all pieces cracked when quenched from temperatures in the cracking zone, and no piece cracked when quenched from temperatures outside these limits. All cracks were longitudinal, *i.e.*, in the direction of rolling and never transverse. It was also found that this cracking zone was quite independent of the size of the test-piece, being the same for thin microsections as for $\frac{1}{8}$ -inch cubes; whilst three steels in the form of 1-inch rounds and 5 inches long cracked when quenched from the danger zone, but did not crack when quenched from 20° above it (see carbide experiments). The author would prefer to study the volume changes in these steels before commenting further.

The Ac_m point was determined approximately in most of the alloys, and Fig. 12 shows these points plotted for a series of steels with 0.80 to 0.90 per cent. carbon and varying chromium. These results will be referred to again in the general discussion.

PART IV.

THE ANALYSIS OF CARBIDES AND RESIDUES.

The circumstances which led the author to believe in the existence of a double carbide of iron and chromium have already been described,⁽⁸⁾ but fuller details may be given at this stage.

A steel with analysis C. 2.62, Cr. 12.40, Mn. 0.50, Ni. 1.07, was found to give a residue on solution in sulphuric acid. This residue had the following analysis : Fe. 46.1, Cr. 42.1, C. 9.0 (?), which on dividing by the respective atomic weights gave $\text{Fe}_{1.00}\text{Cr}_{1.00}\text{C}_{0.91}$. The question naturally arose : Is this a definite compound with the empirical formula FeCrC ?

A small quantity of the above residue was boiled in strong hydrochloric acid until about one-half of it had dissolved ; the remainder was well washed and dried and gave the analysis Cr. 42.0, C. 9.26. A further portion was boiled with nitric acid 1.20, hydrochloric acid added, and about one-half dissolved ; the residue gave an analysis, Cr. 42.1, Fe. 46.0. From this it was concluded that the residue was a definite compound. It should here be pointed out that this conclusion is not necessarily a logical one, but that, from other data, it would appear to be correct. The same compound was obtained from Arnold and Read's steel No. 1093, C. 0.835, Cr. 4.97, but it would be too wearisome to recount the many failures the author has had when attempting to obtain this compound from any other steel.

The method of investigating the constitution of alloys by the examination of residues has fallen into bad repute, owing to the very great difficulty of obtaining concordant results ; but nevertheless there is a fascination in the satisfaction experienced on isolating a compound that can only come from the alloys.

The difficulties would appear to be due to the following causes :

1. The difficulty of getting the bars and the drillings in exactly the same physical condition.
2. If the residue, which is probably more or less attacked by the solvent, should consist of two compounds, it is hardly to be expected that they will both be soluble to the same extent ; so that, unless the current density, strength of acid, &c., are exactly the same in the two experiments the ratio of the two compounds will alter, and therefore the ultimate analysis of the residue.

This may lead to the rejection of the results on the grounds of unreliability, but for some of the ternary alloys it may prove very useful for determining the nature of the compounds. For example, if A and B in Fig. 14 denote the composition of two

compounds, and if, by altering the condition of the experiment, the relative quantities of A and B can be altered, then the point indicating the ultimate analysis of the mixture must lie on the

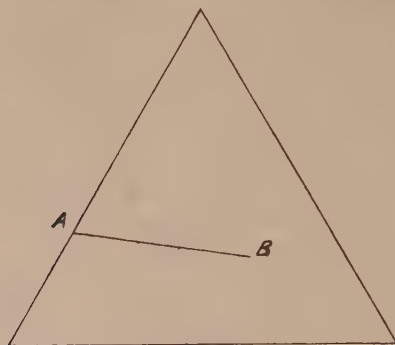


FIG. 14.

line AB and may lead to the identification of these compounds. This will be referred to again later.

The analysis of carbides published by Arnold and Read⁽⁵⁾ have been re-examined in the light of the new compound and Table V. obtained.

TABLE V.

No.	Percentage.		Carbides.						Possible Mixture.
			Percentage.			Atomic Ratio.			
	C.	Cr.	C.	Fe.	Cr.	C.	Fe.	Cr.	
1147	0.64	0.65	7.05	88.58	4.36	0.587	1.582	0.085	85 FeCrC + 500 Fe ₃ C
1090	0.84	0.99	7.23	85.66	7.10	0.602	1.530	0.173	135 FeCrC + 468 Fe ₃ C
1093	0.835	4.97	8.86	45.40	45.74	0.738	0.811	0.897	738 FeCrC + Cr ₁₅₉ Fe ₇₃
1091	0.85	10.15	8.20	28.65	63.17	0.683	0.512	1.238	(?)
1092	0.88	15.02	6.0	34.57	59.41	0.500	0.617	1.165	500 FeCrC + Cr ₆₆₅ Fe ₁₁₇
1148	0.85	19.46	5.40	33.07	61.52	0.450	0.591	1.206	450 FeCrC + Cr ₇₅₆ Fe ₁₄₁
1149	0.85	23.7	5.05	32.12	62.48	0.421	0.573	1.225	421 FeCrC + Cr ₈₀₄ Fe ₁₅₂

It will be seen that, as the percentage of chromium in the steel exceeds 5 per cent., an increasing quantity of iron and chromium remains, in the proportion of approximately five to one, on allocating all the carbon to the double carbide. The

possibility of the presence of an intermetallic compound of chromium and iron can be at once dismissed (see Fig. 18); but, that this excess of chromium and iron is in solid solution, adsorbed, or otherwise mechanically carried down by the double carbide, seems worthy of very careful consideration.

Now Arnold and Read's steels had been very slowly cooled from a bright red heat, with the object of segregating the carbides, and it seemed feasible that if the carbide did carry down excess of chromium and iron, this excess would probably be smaller, if the rate of cooling were quicker, and even smaller still, if all the carbides were retained in solid solution by quenching from a suitable temperature and then reprecipitated by reheating to just below the A_{c1} point.

Of course, the carbide would now be much more finely divided and more readily soluble in acid, but one might sacrifice percentage yield to obtain a purer compound. It was the above line of thought which led to the following experiments being carried out.

DETAILS OF THE METHODS USED FOR THE SEPARATION AND ANALYSIS OF THE CARBIDES.

A quantity of the purest asbestos obtainable was digested in warm concentrated hydrochloric acid for two days, poured into a large funnel with a perforated disc, washed well with water, dried and strongly ignited. The quantity of iron blank was reduced to the equivalent of 0.84 cubic centimetre of N/10 dichromate for each determination. The carbides were separated electrolytically by the method described by Arnold and Read⁽⁵⁾; 5 per cent. hydrochloric acid was used and 0.25 ampere passed for fifteen to sixteen hours.

The residues were obtained from very thin turnings made with the finest cut and traverse on the lathe, and 200 cubic centimetres of a hot mixture of nitric acid (1.20) and dilute sulphuric acid (1 in 5) were poured over 2 to 3 grammes. The reaction was violent but subsided after fifteen to twenty seconds. The solution was now diluted to about 800 cubic centimetres with cold water to prevent further solution of the carbides, and was allowed to stand over night.

In both cases, the insoluble portion was filtered off through

a weighed quantity of asbestos, and after thoroughly washing, &c., was transferred to a porcelain boat. This was put into a hot air oven until nearly dry—about ten minutes—and then burnt off in a current of oxygen and the carbon estimated.

The oxides of chromium and iron remaining in the boat were very intimately mixed with 10 grammes of Stead's tribasic mixture and strongly heated at the back of the muffle for two hours. The mass was dissolved in dilute hydrochloric acid (1 in 5) and made up to 500 cubic centimetres.

The chromium was estimated in 200 cubic centimetres by titration with N/10 ferrous sulphate and potassium dichromate.

The iron was determined in another 200 cubic centimetres by adding ammonia, filtering away practically all the chromium, redissolving the precipitate in hydrochloric acid reducing the iron with stannous chloride and titrating with N/10 dichromate.

This method has the disadvantage that as the weight of the carbide is not known, it is impossible to check the accuracy of the analysis by totalling the percentages, but to collect and dry and weigh the carbide before analysis introduced practical difficulties and error which it was desired to avoid.

Experiments with Steel S with C. 0.84, Cr. 8.59.

1. A piece of the rolled bar 6 inches long, heated slowly to 1250° C., and quenched in water—it did not crack—and reheated to 750° C., turned to $\frac{1}{2}$ -inch round, and decomposed electrolytically. Weight of bar dissolved, 4.85 grammes.

	Total Weight.	Atomic Ratio.	Percentage.
Carbon . . .	0.027927	1020	12.24
Iron . . .	0.058100	455	25.46
Chromium . .	0.142135	1198	62.29

After allocating the requisite carbon to the iron to form Fe_3C there remains $\text{Cr}_{2.76}\text{C}_2 = \text{Cr}_3\text{C}_2$.

2. Last experiment repeated with another piece of the rolled bar quenched from 1150° C.—it did not crack—and reheated to 750° C. Weight of bar dissolved, 6.57 grammes.

	Total Weight.	Atomic Ratio.	Percentage.
Carbon . . .	0.035454	965	11.58
Iron . . .	0.092064	537	30.09
Chromium . .	0.178452	1121	58.33

After forming Fe_3C there remains $\text{Cr}_{2.85}\text{C}_2 = \text{Cr}_3\text{C}_2$.

3. Similar to the last experiment, but the rolled bar heated to 1150° C. and cooled slowly in the muffle. Weight of the bar dissolved, 4.83 grammes.

	Total Weight.	Atomic Ratio.	Percentage.
Carbon . . .	0.026018	967	11.60
Iron . . .	0.078664	610	34.17
Chromium . . .	0.121600	1043	54.22

After forming Fe_3C there remains $\text{Cr}_{2.73}\text{C}_2 = \text{Cr}_3\text{C}_2$. Note the large differences in the ultimate analysis of the carbides, which in each case consists of Fe_3C and Cr_3C_2 .

Experiments with Steel R with C. 0.86, Cr. 5.70.

1. The rolled bar quenched in water from 1250° C.—it did not crack—and reheated to 750° C., decomposed electrolytically. Weight of bar dissolved, 4.743 grammes.

	Total Weight.	Atomic Ratio.	Percentage.
Carbon . . .	0.025909	2159	9.30
Iron . . .	0.152796	2728	54.83
Chromium . . .	0.099950	1922	35.87

After forming Fe_3C there remains $\text{Cr}_{3.07}\text{C}_2 = \text{Cr}_3\text{C}_2$.

2. Three grammes of very fine turnings from the above bar were treated with mixed acids, as already described, and the residue analysed.

	Total Weight.	Atomic Ratio.	Percentage.
Carbon . . .	0.025091	2091	9.61
Iron . . .	0.128548	2295	49.22
Chromium . . .	0.107536	2068	41.77

After forming Fe_3C there remains $\text{Cr}_{3.12}\text{C}_2 = \text{Cr}_3\text{C}_2$.

Up to this point the results had been very satisfactory, but further experiments with a higher percentage of chromium gave rather disappointing results.

Experiments with Steel J with C. 0.79, Cr. 12.1.

1. Rolled bar quenched in water from 1200° C. and reheated to 75° C., decomposed electrolytically. Weight of bar dissolved, 4.635 grammes.

	Total Weight.	Atomic Ratio.	Percentage.
Carbon . . .	0.027000	2250	7.92
Iron . . .	0.059696	1066	17.52
Chromium . . .	0.254030	4884	74.56

After forming Fe_3C there remains $\text{Cr}_{2.58}\text{C}$.

2. Last experiment repeated.

	Total Weight.	Atomic Ratio.	Percentage.
Carbon . . .	0.031364	2614	7.22
Iron . . .	0.156016	2786	35.93
Chromium . . .	0.246868	4749	56.85

After forming Fe_3C there remains $\text{Cr}_{2.82}\text{C}$.

3. Last experiment again repeated.

	Total Weight.	Atomic Ratio.	Percentage.
Carbon . . .	0.028974	2414	7.47
Iron . . .	0.085596	1528	22.08
Chromium . . .	0.273063	5251	70.45

After forming Fe_3C there remains $\text{Cr}_{2.76}\text{C}$.

4. Two grammes of very fine turnings from the above bar were dissolved in mixed acids, as already described, and the residue analysed.

	Total Weight.	Atomic Ratio.	Percentage.
Carbon . . .	0.015300	1275	8.11
Iron . . .	0.071960	1285	38.39
Chromium . . .	0.100206	1927	53.46

After forming Fe_3C there remains $\text{Cr}_{2.29}\text{C}$.

5. Rolled bar cooled very slowly in the muffle from 1200°C . and decomposed electrolytically.

	Total Weight.	Atomic Ratio.	Percentage.
Carbon . . .	0.041454	3454	8.51
Iron . . .	0.122640	2190	25.17
Chromium . . .	0.323134	6214	66.32

After forming Fe_3C there remains $\text{Cr}_{2.28}\text{C}$.

6. Three grammes of very fine turnings from the last bar were dissolved in mixed acids, as already described, and the residue analysed.

	Total Weight.	Atomic Ratio.	Percentage.
Carbon . . .	0.017545	1595	7.32
Iron . . .	0.062776	1121	26.14
Chromium . . .	0.159790	3073	66.55

After forming Fe_3C there remains $\text{Cr}_{2.52}\text{C}$.

At first sight, the experiments with steel J look a very unsatisfactory lot, but when the results are plotted on ternary paper the points lie on a tolerably straight line. This shows, in the author's opinion, that there has been differential solution of two constituents.

The average of the six experiments gives $\text{Cr}_{2.53}\text{C}$, which points to the presence of a carbide Cr_5C_2 . Although the author does not believe that this represents the true state of affairs, he has faithfully recorded the results obtained. Much more work will have to be done.

The author acknowledges with gratitude the valuable help received from Mr. W. M. Gladwin, an assistant in the chemical laboratory of Messrs. Steel, Peech & Tozer, Ltd., in the troublesome isolation and analysis of carbides.

PART V.

THE ELECTRICAL RESISTANCE.

The electrical resistance of all the steels has been determined on a Kelvin double bridge made by Paul.

This had a guaranteed accuracy of one in two thousand. In order to ensure a constant temperature of the bar, the determinations were made while the bars were suspended in an oil bath. Several readings were taken at temperatures in the neighbourhood of 15°C ., and by plotting temperature and resistance and drawing a straight line through the points, the resistance was found at exactly 15°C . to a high order of accuracy.

Fig. 15A shows the knife-edged grips, which were very convenient for suspending the bar in the oil. The knife-edges had been hardened and they left faint marks on the bar, so that the distance between them could be accurately measured after the determination. The thermometer was fastened so that the bulb was in contact with the centre of the bar as shown in Fig. 15B.

Pieces of the rolled bar 8 inches long were turned to $\frac{1}{2}$ inch diameter, and the last layer of turnings were kept for check analysis if necessary. They were well packed in lime and heated to 1000°C . for several hours and allowed to cool in the furnace. They were then turned and accurately finished to 0.47 inch diameter.

For this series the temperature of the oil bath was raised to about 110°C . and readings taken during heating and cooling. The readings on cooling gave the more consistent results.

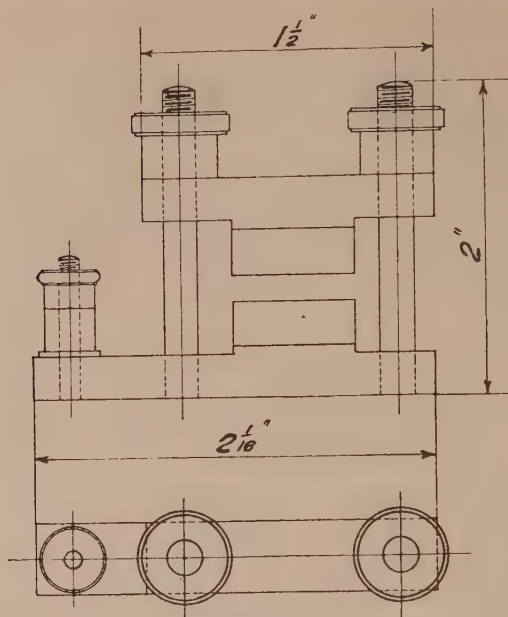


FIG. 15A.

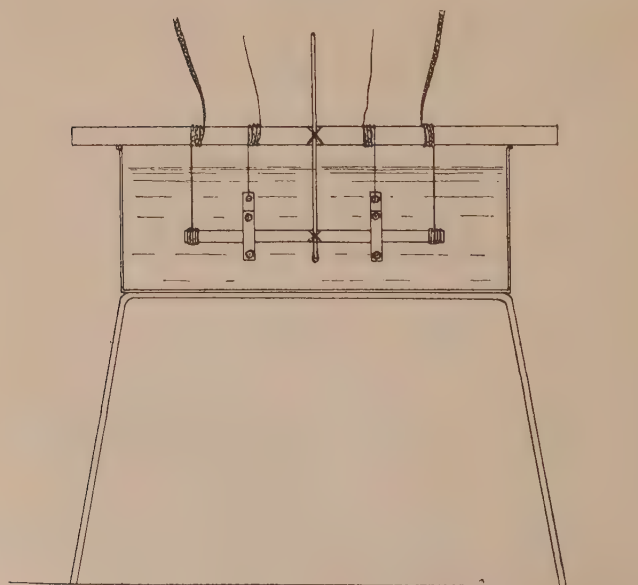


FIG. 15B.

As a matter of interest the temperature coefficient between 15° C. and 100° C. was calculated and is given in Table VI.

$$\text{Temperature coefficient} = \frac{\text{Resist. at } 100^{\circ} \text{ C.} - \text{Resist. at } 15^{\circ} \text{ C.}}{\text{Resist. at } 15^{\circ} \text{ C.} \times 85} \times 100.$$

These bars were now again packed in lime and reheated to 700° C. with the object of throwing out of solution any small quantities

TABLE VI.—*Electrical Resistance of Chromium Steels in Microhms per Cubic Centimetre at 15° C.*

Mark.	Analysis.			After Cooling very Slowly from 950° C.		After Reheating to 720° C.	
	C.	Cr.	Si.	Resistance.	Coefficient.	Resistance.	Corrected for Si only.
A	0.25	1.56	0.049	16.325	0.417	16.80	16.14
B	0.26	3.05	0.035	19.47	0.334	19.30	18.83
C	0.47	6.08	0.051	25.625	0.270	25.76	24.98
D	0.59	8.38	0.086	31.82	0.233	31.76	30.60
E	0.64	12.2	0.150	41.97	0.199	42.11	40.09
F	0.39	1.49	0.043	16.42	0.380	16.16	15.58
G	0.46	3.02	0.066	19.27	0.324	19.16	18.27
H	0.78	6.12	0.088	22.91	0.281	22.86	21.68
I	0.77	9.03	0.092	30.94	0.234	31.05	29.80
J	0.79	12.10	0.169	40.78	0.189	40.78	38.50
K	0.65	1.49	0.073	16.73	0.370	16.58	15.59
L	0.65	3.20	0.073	19.48	0.321	19.36	18.38
M	0.66	6.22	0.056	25.13	0.278	25.15	24.40
N	0.87	8.85	0.103	31.68	0.225	31.77	30.38
P	0.82	1.54	0.050	16.89	0.384	16.77	16.09
Q	0.91	2.96	0.047	18.96	0.343	18.94	18.31
R	0.86	5.70	0.069	21.01	0.310	20.88	19.95
S	0.84	8.59	0.116	29.73	0.233	29.85	28.28
T	1.08	11.36	0.169	37.19	0.204	37.36	35.08
1686	0.50	13.22	0.094	45.09	0.201	44.96	43.69
1687	0.65	13.34	0.060	44.21	0.208	43.80	42.99
1688	0.44	9.00	0.066	36.05	0.227	35.94	35.05
1689	0.50	8.21	0.131	35.46	0.210	35.69	33.92
1690	0.44	5.46	0.051	26.70	0.255	26.47	25.78

of carbide which may have been retained by cooling from 1000° C. The resistances were again determined at 15° C., and it was somewhat surprising to find that these results did not differ materially from those obtained from the first series.

It is usual in conductivity measurements to make corrections for the impurities present; but in alloys of this type, with large

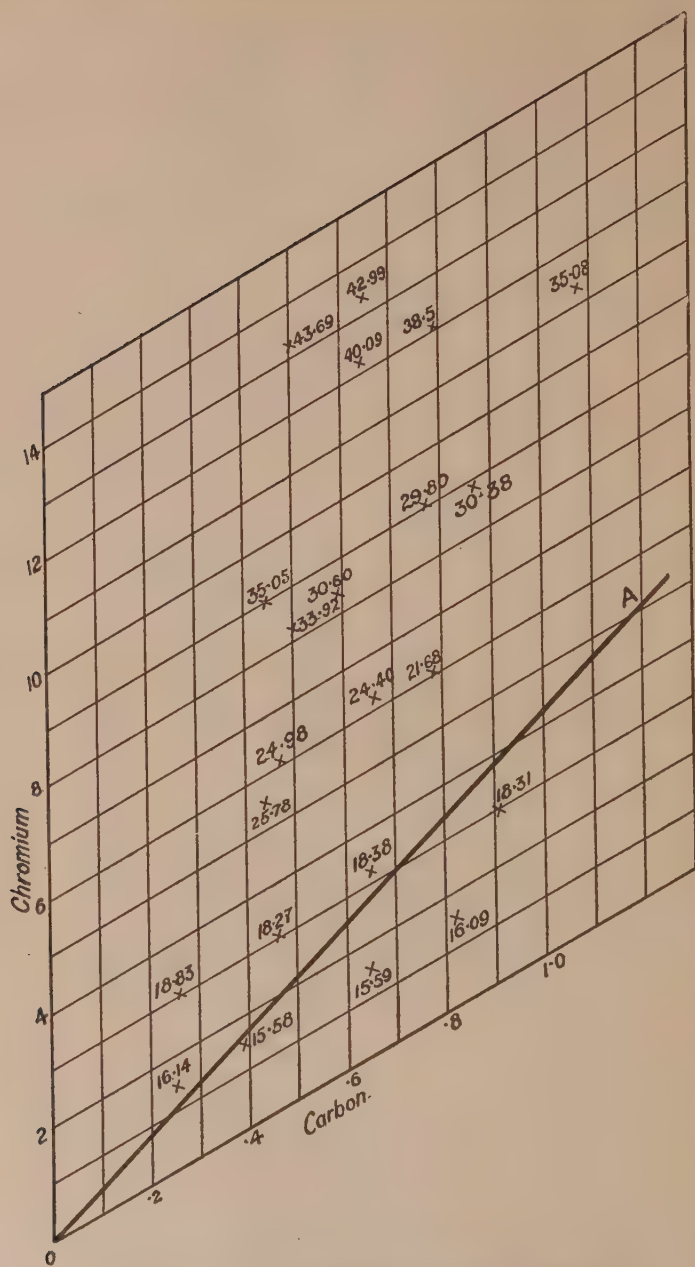


FIG. 16.—Specific Resistances—Corrected for Silicon only.

quantities of an element in solid solution in the iron, it is questionable how far these so-called corrections are justified or necessary. The correction for manganese, for instance, is usually made a negative one, but when 0.10 per cent. manganese is associated with up to 0.15 per cent. sulphur it is evident that the correction should be a positive one.

For silicon, Edwards and Norbury give 13.5 as the best figure for the increase in resistivity due to 1 per cent. in silicon steels. But is it correct to use this figure when the silicon is associated with up to 12 per cent. chromium? It is a debatable point, but a column has been added with the resistivities corrected for silicon on this basis.

All the results are given in Table VI., and shown on triangular co-ordinates in Fig. 16. The results are considered in more detail in the general discussion.

PART VI.

CONCLUSIONS, GENERAL DISCUSSION, AND CRITICISMS.

General Form of the Model.

From points in a triangle representing the composition of the steels, vertical ordinates were raised and marks indicating the carbon change point, approximate cementite point, and the burning temperature were made on each one. This left no doubt as to the general form of the model, although many more steels will have to be examined before certain important lines can be definitely determined.

Figs. 17 and 18 show the Fe-Fe₃C and Fe-Cr⁽⁶⁾ equilibrium diagrams. The points S and A denote the limits of solid solubility of carbon and chromium in gamma-iron at these temperatures.

When both carbon and chromium are present, the percentage of each required to saturate gamma-iron will be denoted by a line joining S to A, shown in plan on Fig. 19.

The general direction of this line is indicated on Fig. 23. The solidus-surface, of course, passes through L-S-A.

The whole of the author's series, with the exception of T, fall

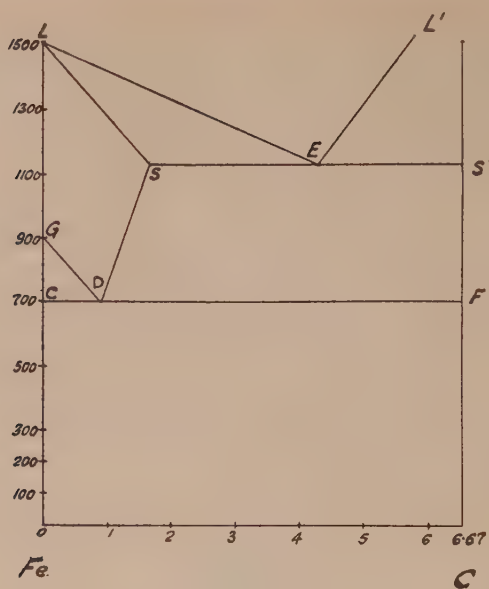


FIG. 17.

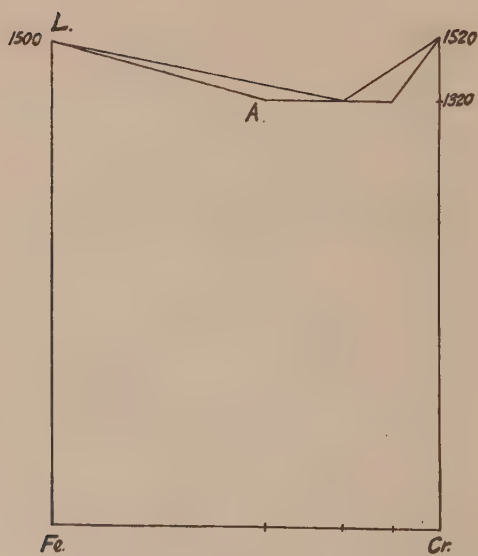


FIG. 18.

The contour of the eutectoid plane is referred to when considering the recalescence data.

The *Excess-Carbide Surface* joins DI with SA.

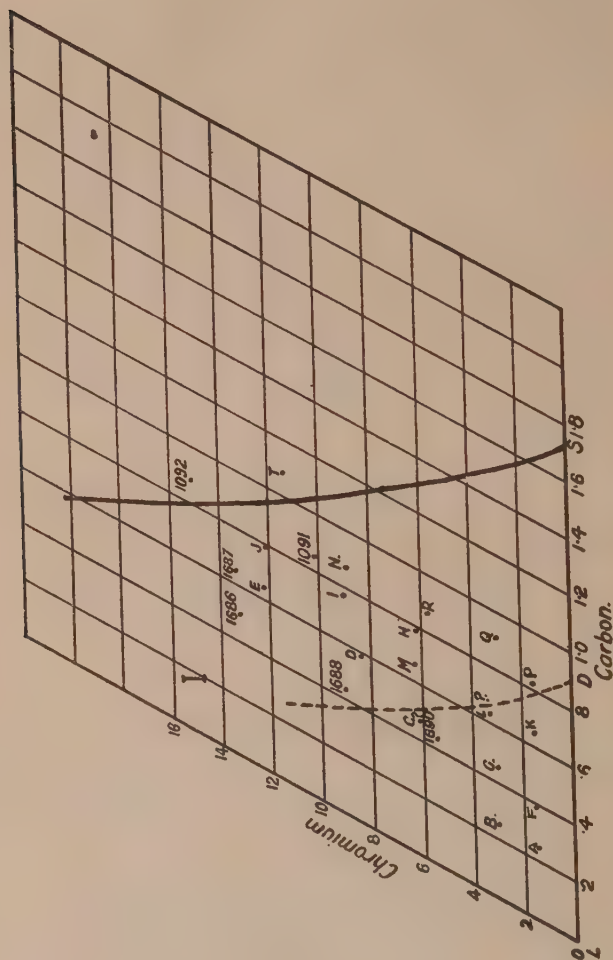
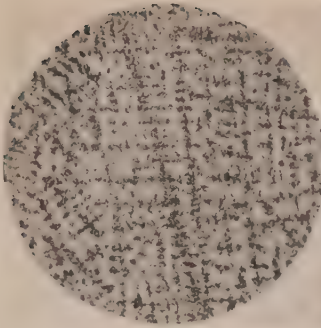


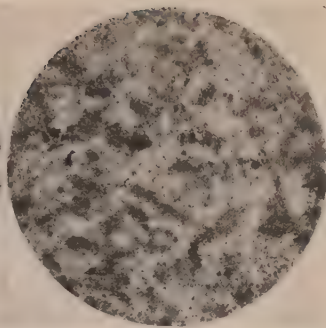
FIG. 20.

The *Excess-Ferrite*, or *Chromiferous-Ferrite Surface* passes through DI and G.

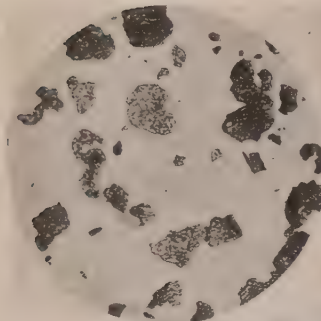
The microscopic examination is in full agreement with this.



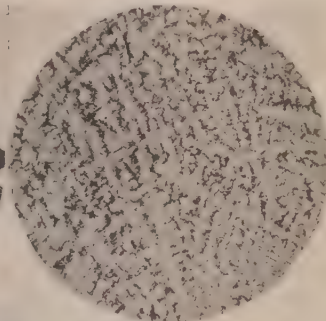
No. 1.



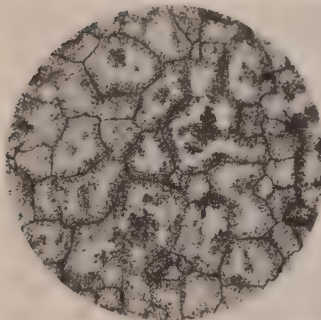
No. 2.



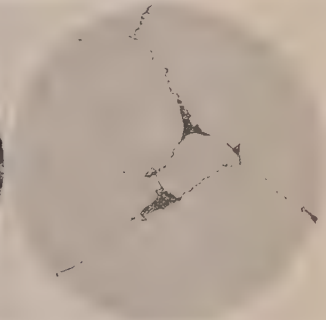
No. 3.



No. 4.



No. 5.



No. 6.

- No. 1. Typical "as rolled" Cr Steel. Etched with Cu reagent. $\times 50$ and reduced.
- No. 2. Steel "G." C .46 Cr 3.02. Heated to 830° . Quenched at 770° . Etched with Cu reagent. $\times 50$ and reduced.
- No. 3. Same as No. 2. $\times 500$ and reduced.
- No. 4. Steel "R." C .86, Cr 5.7. Etched with Murakami's reagent. $\times 50$ and reduced.
- No. 5. Steel "J." C .79, Cr 12.1. Burnt—No eutectic. Etched with 1% HNO_3 in Picric. $\times 50$ and reduced.
- No. 6. Steel 1092. C .88 Cr 15.0. Burnt—Eutectic. Etched with Cu reagent. $\times 500$ and reduced.

MICROSCOPIC EXAMINATION.

The microscopic examination of the rolled bars, both before and after quenching from just above the Ac_2 point, proved very instructive, and gave much information about the nature of these alloys. All the hyper-eutectoid steels can be put into one class, and it will be sufficient to describe in general terms a typical case.

When such an alloy cools from the liquid state it follows the ordinary laws of dendritic crystallisation. The crystallites contain less carbon and chromium than the melt, and there is a gradual increase of carbon and chromium until the crystal is built up. This gradation of concentration gives rise to a cored structure. Usually a sufficiently long heating just below the solidus will cause complete diffusion. The persistence of a cored structure, particularly in the high chromium steels, when etched with copper reagent after prolonged heating at high temperatures, was one of the features of these steels.

Bearing in mind the delicacy of the test, the comparatively large differences in concentration, and the slowness of the diffusion, it may be assumed that the cored structure would be completely destroyed if the steels were kept long enough at the proper temperature.

It was found fairly easy to diffuse the carbide, more or less evenly, by heating to above the solution point and maintaining for some time. But, as a matter of fact, in these rolled bars either the temperature had not been high enough, or the time long enough, to diffuse the carbide, with the result that it had deposited as it were *in situ*, *i.e.*, the bulk of the carbide was always found in the interdendritic fillings.

This is seen in Micrograph No. 4, Plate XXIII., which shows an "as rolled" steel etched with Murakami's reagent.

The only effect of increasing carbon and chromium within the limits of the series is to increase the quantities of the carbide.

In none of the steels was any evidence of two carbides found, the only difference in the carbide grains was due to size. They would appear as small globules in the inter-fillings and gradually get smaller, so that, in the spines of the crystallites, they were only visible under an oil immersion objective.

DISTRIBUTION OF THE CHROMIUM AS SHOWN BY THE RESISTIVITY AND CARBIDE TESTS.

The resistivity tests in themselves prove nothing. At least another fifty alloys in this narrow range would be necessary before any definite conclusion could be drawn.

As far as they go they support the theory that, on adding chromium to a plain carbon steel the chromium first associates itself with the carbide until the chromium to carbon ratio is about 4·3, which corresponds to a carbide with the empirical formula FeCrC , and probably only a small percentage of chromium goes with the ferrite. With further additions of chromium, the bulk goes into solid solution with the iron and therefore raises the electrical resistance.

This is readily seen in Fig. 16 by drawing lines through constant carbon percentage and noting how the specific resistance increases rapidly when the line OA is passed; which supports in every particular the conclusions of Edwards and Norbury⁽³⁾ for annealed steels.

That some of the chromium, even when the 4·3:1 ratio is passed, is associated with the carbide is proved by the usual carbide tests, notably those published by Arnold and Read and the view is widely held that another carbide with a higher chromium content than Cr_3C_2 is formed (see Arnold and Read, Murakami, Edwards).

The present author, however, is inclined to the view that the excess chromium, and probably some iron, is carried down either mechanically, or more probably in solid solution with the carbide.

In steel R with Cr-C, ratio 6·63:1, and steel S with Cr-C, ratio 10·2:1, he has by suitable heat treatment reprecipitated these carbides in a purer form, and shown conclusively that the carbide involved is Cr_3C_2 . (See Carbide tests.)

A similar attempt with steel J, Cr-C, ratio 15·3:1, failed.

PROBABLE EXPLANATION OF THE ISOTHERMAL-EUTECTOID LINES.

By assuming that the views already expressed as to the nature of carbide and the distribution of the chromium are correct, it is possible to deduce the theoretical isothermal eutectoid lines.

In Fig. 21, which has purposely not been drawn to scale, if A denotes the compound Fe_3C and O denotes the compound FeCrC , then every possible mixture of FeCrC and Fe_3C can be denoted by some point on AO; *e.g.*, B denotes the ultimate analysis of AB parts FeCrC and BO parts of Fe_3C , which are supposed to be in solid solution with one another.

If now the iron and the carbide B, up to a certain percentage

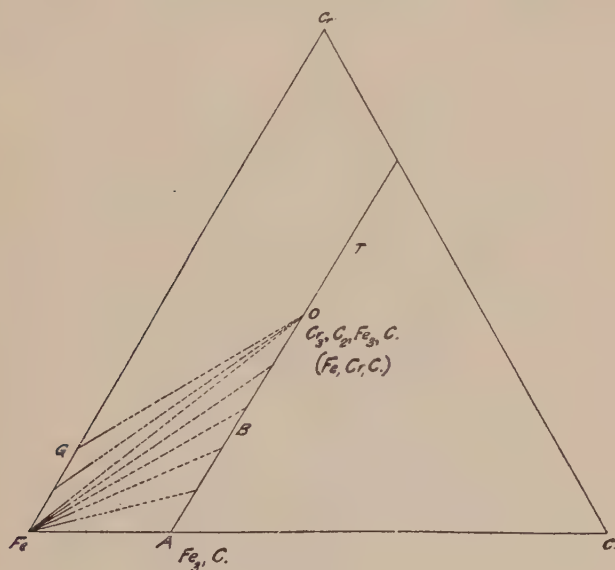


FIG. 21.

of B, form a simple eutectoidal series, quite similar to Fe and Fe_3C , then FeB would be an isothermal eutectoid line.

Similarly, a point G may denote a solid solution of chromium in iron of definite concentration, and if the solid solution G and the compound O—up to a certain percentage of O—form a simple eutectoid series, then the line GO would be an isothermal eutectoid line.

In the latter case it may be that the carbide would be more accurately indicated by a point beyond O in the direction OT, but this would not seriously affect the result.

On Fig. 11 a few of these theoretical lines have been drawn

and it is seen how accurately the determined figures fall into their proper places.

The contour of the eutectoid, or pearlite, or carbon change surface is best understood by reference to Fig. 11, on which has been drawn what the author believes to be the true isothermal eutectoid lines.

GUILLET'S CLASSIFICATION OF CHROMIUM STEELS.

In 1903, Leon Guillet⁽⁹⁾ published a classical research on special steels, and in a brilliantly conceived attempt to depict

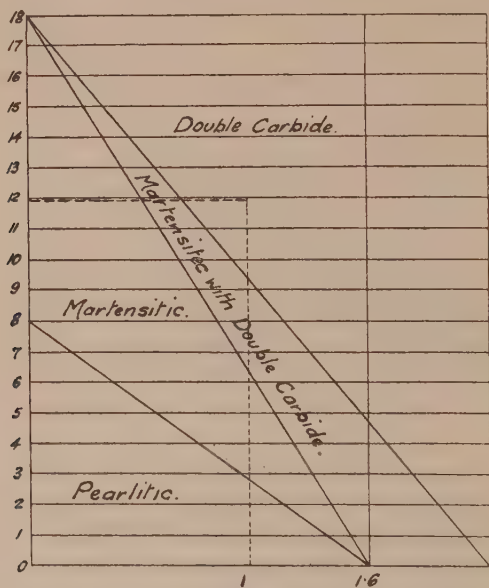


FIG. 22.

graphically the effect of special elements on the microstructure evolved a series of diagrams which show this at a glance.

His diagram for chromium steels is reproduced in Fig. 22. The present author's series of steels cover the area shown by dotted lines, and in every case the steels are pearlitic when cooled at the rate shown on Fig. 6—all the steels recalesced between 700° C. and 770° C.

On the other hand, many steels in Guillet's pearlitic area can be readily made martensitic by air cooling small pieces. It is evident that the relative areas of pearlite and martensite are capable of wide variation, and that Guillet's diagram does not represent the stable equilibrium of these steels.

The double carbide referred to by Guillet is interesting, as it is now possible to say that it is the original carbide of the ternary eutectic which is contained in all steels lying to the right of the line SA, Fig. 19.

THE IMPORTANCE OF DIFFUSION.

The importance of diffusing these chromium-carbon alloys to obtain equilibrium before building up the thermal equilibrium model has already been referred to, but must be emphasised here. An alloy with a composition represented by a point near to, but on the left side of, the line SA, Fig. 19, would not contain any eutectic when in equilibrium; but when such an alloy is cooled from the molten state, the chromium diffuses so slowly that the last portions to solidify would have a composition represented by a point on the right of SA, and would therefore contain a eutectic.

In this respect it would be analogous to the phenomenon which is sometimes found in the non-ferrous binary systems. An "as cast" α -brass may show β solid solution in the inter-fillings, but after suitable annealing, or diffusing, would all consist of α solid solution. This is apparently what has happened in a research by Oberhoffer and Daeves⁽⁷⁾, whose diagram for the appearance of the eutectic is shown in Fig. 23. There is such a wide discrepancy between this line and the one found in the present work that it is with a certain amount of personal diffidence that the author ventures to criticise before he has examined the "as cast" structures.

There are, however, no less than fourteen samples in the present series which lie to the right of Oberhoffer's line, and in which it is possible to obtain all the carbides in solid solution. Therefore they cannot contain a eutectic when in the stable state. See Fig. 12, also Micrograph No. 5, Plate XXIII., of steel J, burnt—no eutectic; and Micrograph No. 6, of steel 1092, burnt—eutectic.

The only conclusion is that Oberhoffer's series were not properly diffused, although he states that steps were taken to ensure equilibrium.

In the author's series, diffusion would be assisted by the preliminary rolling which would break up the eutectic.

It is probable that differences in concentration of the chromium and carbon is also an explanation of the statement made by Monypenny,⁽¹⁰⁾ who writes: "Part of the carbide forming the

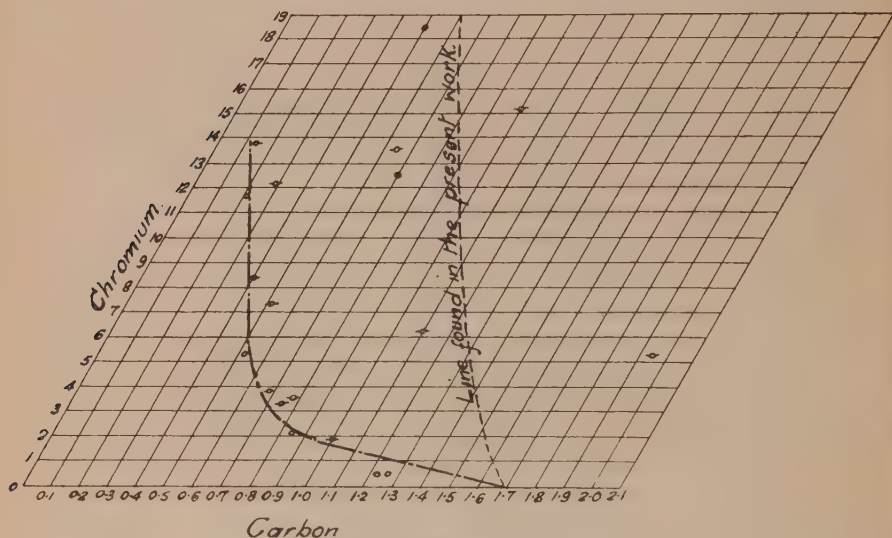


FIG. 23.

pearlite in the annealed or tempered condition does not dissolve at A_{c1} , but progressively during a considerable range of temperature above this point."

The present author has already pointed out that this is true for the "as rolled" or undiffused bars, but as far as his series of steels go, he cannot agree that there is any appreciable range for a perfectly diffused bar, indeed, it would be quite contrary to the nature of a eutectoid.

The point, however, has considerable practical significance, as it is quite unnecessary to diffuse the constituents before commercial heat treatment.

The author wishes to thank all with whom he has come in contact in connection with the research, for the way in which they have made the work easy and pleasurable by the many kindnesses and considerations shown.

His special thanks are due to the directors of Messrs. Steel, Peech & Tozer, Ltd., and to Mr. E. H. Saniter, for permission to carry out the research and to publish the results; to Messrs. Peter Stubs, Ltd., for making the first series of research steels; to Professor C. H. Desch, D.Sc., and Mr. F. K. Knowles, M.Met., of the Department of Applied Science, Sheffield University, for making the second series of steels; to Mr. B. W. Methley, F.I.C., and his staff for analysing the bars; and finally he acknowledges his special indebtedness to the staff of the Research Department—his chief, Dr. T. Baker, M.Met., F.I.C., and his colleagues, Mr. B. Lackenby, Mr. J. Stead, M.A., and Miss M. K. Aston—all of whom have shown the deepest interest in the work, and by material assistance have contributed to the report.

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VISITS AND EXCURSIONS AT THE PARIS MEETING.



THE invitation to the Iron and Steel Institute to hold its Autumn Meeting in France was originally received in 1919 from the President, Mr. Eugène Schneider, on behalf of the members of the Board of Control of the Comité des Forges de France, the proposed date of the meeting being September 1920. The industrial situation in France that year having, however, been unfavourable, the invitation was renewed for the current year, and an extensive programme of visits and excursions was drawn up by Mr. R. Pinot, the Secretary of the Comité des Forges, with the collaboration of the directors and owners of many of the principal iron and steel works. This programme, so far as the excursions into Lorraine were concerned, followed closely the original scheme proposed for the Autumn Meeting of 1914, which, owing to the outbreak of the Great War, had to be abandoned.

The constitution of the Board of Control of the Comité des Forges de France, who were the hosts of the Institute, is as follows :

Honorary President :

EUGÈNE SCHNEIDER.

President :

FRANÇOIS DE WENDEL.

*Vice-Presidents :*A. DREUX.
PRALON.

R. PINOT.

LÉON LÉVY.
TH. LAURENT.*Treasurer :*

Baron XAVIER REILLE.

*Members of the Board :*AUBRUN.
AYNARD.
BETHMONT.
CH. BOUTMY.
CAVALLIER.
G. CLAUDINON.
DARCY.
DUMUIS.
E. FERRY.
R. FOULD.GRIOLET.
HEURTEAU.
P. LABBÉ.
L. MERCIER.
Baron L. DE NERVO.
Baron PETIET.
H. PETIN.
R. PINOT.
J. SCHNEIDER.
H. DE WENDEL.*Honorary Members :*DE COURVILLE.
FAYOL

DE FREYCINET.

Secretary :

DESPORTES DE LA FOSSE.

Statistics and Technology :

DE CHARNACÉ.

Establishment Manager :

P. PEISSI.

To the foregoing Comité and to the directors and managers of the various works in Lorraine, Burgundy, and Normandy which were visited during the meeting, the warm thanks of the members are due, and the Council, in this connection, desire to place on record their indebtedness to Mr. Eugène Schneider, their immediate Past-President, Honorary President of the Comité des Forges ; to Mr. François de Wendel, President of the Comité des Forges ; to Mr. R. Pinot, who in the earlier stages of the arrangements was General Secretary of the Comité (of which he has

since been appointed a Vice-President) ; to Mr. Desportes de la Fosse, the Secretary of the Comité, and to Messrs. Peissi and de Charnacé, staff superintendent and chief technical and statistical secretary respectively of the Comité, all of whom rendered the greatest services in making the meeting a success. The Council wish likewise to take this opportunity of expressing their thanks to the President, Marshal Foch, the Vice-Presidents, and the members of the Cercle de l'Union Interalliée ; to Mr. E. Herriot, the Mayor of Lyons and Senator of the Rhone ; to Mr. A. Lignon, President of the Committee of Lyons Fair ; to Messrs. C. Cabaud and A. Rivoire, Vice-Presidents of that Committee ; to Mr. A. Victor, the General Manager of the Fair, and to the Members of the Town Council of Lyons and of the Fair Committee ; to the Mayor and Town Council of the City of Caen ; to Mr. Famechon, Director of the National Department of Tourisme of the Ministry of Public Works ; to Mr. Dorand, Director of the Compagnie Française de Tourisme, to Mr. Romain of that company, and Mr. Vignon, the representative in London of the Department ; and to the directors and officials of the Paris, Lyons, and Mediterranean Railway Company, the Eastern Railway Company of France, and the State Railways, as well as to the Board and officials of the South Eastern and Chatham Railway Company and of the Northern Company of France. In this latter connection, the Council wish particularly to thank Mr. Coucherousset of the P.L.M., Mr. Mermont of the Est., Mr. Armand of the État, Mr. F. A. Brant and Mr. A. H. Bourn of the South Eastern and Chatham Railway, Brigadier-General Hildyard, D.S.O., and Mr. Livesey of the Paris Office of that Railway ; Mr. Trarieux, the company's representative at Boulogne, and Mr. Delautre of the Northern Company of France, Stationmaster at Boulogne. The Institute has also to place on record its indebtedness to the French Embassy in London, to Mr. Bonzon, Consul-General of France in London, for the special privileges so kindly accorded in regard to customs examinations, and to Mr. Billecocq, his assistant, as well as to the British Embassy in Paris for its assistance in connection with the reception of the Council by the French President, Mr. Millerand.

The attendance was exceedingly gratifying, over 200 members and ladies having travelled by the special train leaving Victoria

on the morning of Sunday, September 4, while between fifty and sixty members travelled to Paris independently, and the numbers were further increased by French members and members from other countries, the total attendance having been approximately 350. The Secretary's office was situated at the headquarters of the Comité des Forges, 7 rue de Madrid, an imposing suite of offices, containing on the ground floor an extensive and well-lighted theatre capable of seating between three and four hundred persons. The meetings themselves were held on the mornings of Monday and Tuesday, September 5 and 6.

The main body of members who availed themselves of the special arrangements made by the Institute on their behalf, left London at 9.50 A.M. by special train on the morning of Sunday, September 4. On arrival at Boulogne they were distributed for luncheon at the Buffet of the Maritime Station, the Hôtel du Louvre and the Hôtel Castiglione on the southern side of the harbour, and at the Hôtel Christol on the northern side, the special train conveying them from the Maritime station to these hotels and returning to transport the members who had lunched at the Buffet. The special train left Boulogne at 3.10 P.M. for Paris, which was reached punctually at 6.40, whereupon the members proceeded to the various hotels allotted to them, which were the Grand Hôtel du Louvre, the Hôtel Terminus Saint Lazare, the Hôtel du Palais d'Orsay, and the Hôtel Moderne.

Those attending the meeting registered their names at the Secretary's office at the Comité des Forges on the morning of Monday, September 5, and received the necessary tickets, labels, &c., as well as the badge, which consisted of a reproduction of the arms of Paris, in gilt and coloured enamel, surmounted by a mural crown in gilt, and surrounded by a scroll bearing the inscription "IRON AND STEEL INSTITUTE, PARIS, 1921," in gilt letters on white enamel, the design of which is reproduced on p. 297.

The official proceedings commenced on the morning of Monday, September 5, in the Lecture Hall of the Comité des Forges under the Presidency of Sir Hugh Bell, Bart., Past-President, who, in the regretted absence of Dr. J. E. Stead, F.R.S., President, through ill-health, had kindly consented to take the Chair.

Mr. François de Wendel (President of the Comité des Forges) welcomed the Institute and referred to the previous visit it had

paid to France in 1900, on the occasion of the Paris Exhibition. Sir Hugh Bell expressed on behalf of the Iron and Steel Institute his thanks to Mr. de Wendel and to Mr. Schneider and his colleagues of the Comité des Forges for their kind invitation and warm welcome, after which he presented the Bessemer Medal for the year to Mr. Charles Fremont, to whom the Council had unanimously awarded it in recognition of his great services to metallurgy, and, more particularly, for his classical work in regard to impact tests. Professor Louis, Member of Council, read in French an account of Mr. Fremont's work, after which papers by Mr. P. Nicou and by Mr. A. Guillaïn were read and discussed. A more detailed account of these proceedings will be found on pp. 1-13.

The proceedings were then adjourned to the following day when, on the conclusion of the more formal business of the meeting, papers were read by Mr. Guillet, by Mr. Dupuy, by Mr. Cohade (who communicated a paper by Mr. E. Schneider), and by Mr. Portevin in collaboration with Mr. Chevenard.

The proceedings concluded with the customary votes of thanks to the Institute's hosts, and a special vote of thanks, proposed by Sir Robert Hadfield, Bart., F.R.S., Past-President, and by Mr. Illtyd Williams, Honorary Treasurer, to Sir Hugh Bell for presiding.

VISIT TO THE GRAVE OF THE UNKNOWN WARRIOR.

At 3.30 P.M. on the afternoon of Monday, September 5, a number of members assembled at the Arc de Triomphe in the vicinity of the grave of France's unknown warrior (*le Poilu inconnu*), upon which Mr. Guy Barrett deposited, on behalf of the President, Council, and Members of the Institute, a floral tribute. This took the form of a beautiful wreath of natural flowers, to which was attached a tricolour ribbon bearing in gilt letters the words "Iron and Steel Institute." The occasion was made an entirely informal one, and was confined to the simple act of laying the wreath upon the stone slab which covers the unknown soldier's grave, as it was not thought advisable to detract from the simplicity of the function by making it an occasion for any more formal proceedings.

RECEPTION AT RAMBOUILLET.

The President of the French Republic, having graciously consented to receive a deputation of the Council of the Iron and Steel Institute at his country seat at Rambouillet on the afternoon of Monday, September 5, those forming the deputation assembled at the Hôtel du Louvre, in the Place de Théâtre Français, at 2.45, and proceeded to Rambouillet in five large Renault cars. Rambouillet is situated some thirty miles south-west of Paris, on the southern borders of the Forest of that name. The first stages of the journey were through the Bois de Boulogne and St. Cloud, where the way rises steeply up to the beautifully terraced gardens and wooded heights overlooking the river, and thence through Versailles. Thereafter the road follows closely the line of the Paris-Orleans Railway for some miles before descending towards the confines of the Forest of Rambouillet. The Palace itself dates back to the fourteenth century, and has numerous historical associations of the greatest interest, Francis I. having died there in 1547, and Catherine de Medicis having found an asylum there during the religious wars. In later times it was used as a royal hunting-box, and it was here that Charles X. signed his abdication of 1830.

On their arrival at the Château they were met at the main entrance by Mr. François de Wendel, Mr. Schneider, and Mr. Pinot, who had preceded the party, and were introduced by the military aide-de-camp to the President, who received them in the drawing-room, where Sir Hugh Bell, addressing him in French, expressed his sense of the honour which had been done the Institute by granting an audience to the Council, and dwelt on the pleasure it afforded the Institute to meet with so many marks of kindness and goodwill from its French hosts. Mr. Millerand addressed a cordial speech of welcome to the members, and emphasised the need for mutual understanding and forbearance between England and France with regard to the various problems with which each country was faced. Madame Millerand then joined the party, and after the members of the deputation had been presented to her, led the way to the adjoining apartments, where tea was served. The absence of formality and the kindly hospitality evinced rendered the reception a memorable

and unique occasion amongst the many with which the Institute has, on the occasion of previous meetings, been honoured in other countries. The following had the honour of being received by the President : Sir Hugh Bell, Bart., *Past-President* ; Mr. F. Samuelson, *President-Elect* ; Sir Robert Hadfield, Bart., F.R.S., *Past President* ; Mr. Eugène Schneider, *Past-President* ; Mr. F. de Wendel, *President of the Comité des Forges* ; Mr. R. Pinot, *Vice-President, Comité des Forges* ; Sir W. H. Ellis, G.B.E., *Vice-President* ; Mr. E. Steer, *Vice-President* ; Mr. Iltyd Williams, *Hon. Treasurer* ; Col. N. T. Belaiew, C.B. ; Mr. A. Greiner ; Mr. F. W. Harbord, C.B.E. ; Mr. G. Hatton, C.B.E. ; Mr. Alfred Hutchinson ; Prof. H. Le Chatelier ; Prof. Henry Louis ; Mr. J. Payton ; Mr. G. C. Lloyd, *Secretary* ; and Mr. L. P. Sidney, M.B.E., *Assistant Secretary*. At the conclusion of the repast the President and Madame Millerand again shook hands with their guests and withdrew, whereupon the party dispersed, the British members of the deputation returning to Paris.

Although not extensive, the reception rooms of the Palace of Rambouillet are extremely beautiful, and possess magnificent carvings and priceless tapestry, some of which is Gobelin and some from the far-famed looms of Beauvais. The latter, despite their antiquity, still exhibit their original purity of tone and colour, and are amongst the most splendid specimens existent.

RECEPTION BY THE COMITÉ DES FORGES.

In the evening the members were entertained by the Comité des Forges at a reception which was held at the Hôtel de l'Union Interalliée, a beautiful building in the Rue du Faubourg St. Honoré, the ground floor of which consists of numerous suites of rooms devoted to the original purposes of the Union, which was to afford a place of meeting for members of the countries allied in the recent war to meet together for social converse.

The reception was preceded by a dinner given in the Club portion of the premises, by the Board of Direction of the Comité des Forges, to the Council of the Iron and Steel Institute. Mr. F. de Wendel presided as chairman, and Mr. E. Schneider as vice-chairman. Mr. Loucheur, Minister of the Liberated Regions, and Mr. Dior, Minister of Commerce and Industry, were invited,

but Mr. Loucheur unfortunately was unable to attend. Mr. F. de Wendel, who had Sir Hugh Bell, Bart., Past-President, on his right, expressed the pleasure he felt in being able to welcome the members of the Council to Paris, and spoke of the cordial relations which for many years had existed between the iron trade leaders of France and England. Sir Hugh Bell in his reply thanked Mr. de Wendel, the Comité des Forges, and the Committee of the Union Interalliée for their kindness and hospitality, and expressed his confidence in the immediate future of the industry, once the problems which faced it, and were in process of solution, were solved. He proposed the toast of the Committee of the Club, and of its distinguished guest, Monsieur Dior, who replied briefly, thus bringing the proceedings to a close, after which the company joined the gathering in the rooms below, where a most highly artistic entertainment had been kindly prepared by the hosts for the visiting members of the Institute, and the ladies by whom they were accompanied.

The programme of music performed by the orchestra of the Club, and numbers of eminent artists and artistes from the Opera contributed to the enjoyment of the evening under the direction of Mr. Staats, the Ballet Master of the Opera. Mlles. Craponne, Daunt, H. Dauwe, S. Dauwe, and Valsi gave an exhibition of classical dancing, and Mlles. Monsy and Todorova rendered selections from "La Traviata" and other operas, the performance concluding with a sketch in which Mr. Staats and Mlles. Daunt, Valsi, and Dauwe took part, entitled "Le Chasseur Noir." At the conclusion of the performance refreshments were served to the guests, after which dancing took place until a late hour, the whole occasion being one which was greatly enjoyed by those present.

VISIT TO THE GRAVE OF SIDNEY GILCHRIST THOMAS.

A few weeks prior to the meeting, Dr. Léon Guillet took occasion to remind the Council that Sidney Gilchrist Thomas, the inventor of the basic process which bears the name of Thomas all over the Continent, who died in Paris in 1885, was interred in the cemetery of Passy.

It was accordingly resolved that it would be most appropriate

to pay respect to his memory at some convenient time during the period of the Autumn Meeting in Paris, and at midday on Tuesday, September 6, after the conclusion of the morning session in the rooms of the Comité des Forges de France, a deputation consisting of Sir Hugh Bell, Bart., Acting-President of the Meeting ; Sir Robert Hadfield, Bart., F.R.S., Past-President ; Mr. F. Samuelson, President-Elect ; Mr. F. W. Harbord, C.B.E. ; Professor Henry Louis ; Mr. A. C. Meyjes ; Mr. J. Horton, and others proceeded to the cemetery, where, under the guidance of Dr. Guillet, they visited the grave and deposited a wreath of oak-leaves in bronze, bearing the following inscription :

“ IRON AND STEEL INSTITUTE—SEPTEMBER 5, 1921.

“ To the memory of Sidney Gilchrist Thomas,
Metallurgist and Inventor of the Thomas Process
for the manufacture of Steel.”

By permission of his sister, Mrs. Thompson, it has been arranged that the wreath should be attached permanently to the cross forming the headstone of the grave.

A brief note containing an appreciation of the life and work of Thomas was handed to those present, and the party having paid this tribute to the memory of their distinguished countryman, returned to the city and dispersed soon afterwards to join the several excursions which were leaving Paris that afternoon for different destinations.

VISIT TO CHOISY-LE-ROI.

A number of members accepted the invitation to visit the works of Messrs. Bonvillain & Ronceray at Choisy-le-Roi, carriages being kindly provided for their conveyance to the works, which are situated some ten miles south-east of Paris. On arrival they were welcomed by the heads of the firm and conducted over the works, which are devoted principally to the manufacture of foundry appliances, moulding machines, &c.

VISITS TO PLACES OF INTEREST AROUND PARIS.

The members and ladies who remained in Paris in preference to going on one of the long-distance excursions were taken on
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Wednesday to Fontainebleau, on the afternoon of Thursday to St. Germain-en-Laye, and on Friday to Versailles, the journey to Fontainebleau being made by railway, while the other places were visited by automobiles. The whole of the arrangements were placed in the hands of the Compagnie Française du Tourisme, who spared no pains to render the visits most successful and enjoyable. The weather throughout was perfect, and the party, which numbered fifty, were everywhere received with the greatest kindness and cordiality.

In each instance motor vehicles were in attendance at the principal hotels for the conveyance of the party, who, on the morning of Wednesday, September 7, proceeded to the Terminus of the P.L.M. railway, whence they travelled by train to Fontainebleau, which was reached shortly after midday. Luncheon was served at the Hôtel François I., which is in close proximity with the Castle and Forest of Fontainebleau, after which they visited the Castle, and were taken for a drive through the Forest.

The Château of Fontainebleau was the favourite hunting-seat of the Kings of France for over 600 years, and the State apartments rival in point of beauty those of Versailles. The Forest of Fontainebleau is 63 miles in circumference and covers 42,000 acres. The villages in its vicinity are the favourite resorts of artists, and while a really extensive stay is necessary in order to view the many beauties of the Castle and Forest, the drives afforded the means of seeing some of the more beautiful points.

The return train left Fontainebleau at a quarter past six, Paris being reached at half past seven, whereupon the visitors were taken back to their hotels for dinner.

On the afternoon of Thursday, September 8, the members and ladies accompanying them were driven to St. Germain, *via* the Bois de Boulogne, to visit the Palace and Park, as well as the Château de Malmaison, with its beautiful grounds and terraces. Tea was served at that favourite resort of Parisian pleasure, the celebrated Hôtel du Pavillon Henry IV., on the terrace overlooking the river, from which the view extends over many miles of charming scenery and embraces part of Paris itself.

The Château of St. Germain, formerly a Royal Palace, and at a later period the abode of James II. after his abdication, is now a National Museum, containing historical collections of unrivalled interest. The Park and Forest is one of the largest in the environs

of Paris, and covers an extent of 11,000 acres, laid out in magnificent avenues, and fringed with flower-beds and shrubberies along the edge which borders the high ground overlooking the Seine valley.

Friday, September 9, the last day of the meeting, was devoted to a visit to Versailles, the members leaving Paris in motor vehicles at 9.30 A.M. to drive, *via* Sevres, to their destination. The forenoon was spent in visiting the celebrated Palace, which is far too well known to need description, but which had for the visitors the added interest attaching to the memorable days of its recent history, when it was the scene of the peace negotiations and treaty which terminated the late war. Luncheon was served at the famous Hôtel des Reservoirs, and the afternoon was devoted to drives in the Forest, to visits to the two Palaces of the Trianon, to the historic museum of State carriages, and to the model dairy and farm installed by Louis XVI. for Queen Marie Antoinette.

The return to Paris at 7 P.M. concluded the programme of drives and excursions which had been provided, and brought the proceedings to a close.

Opportunity may here be taken to express the thanks of all those who took part in these excursions to the Compagnie du Tourisme Française for the admirable way in which they were organised. Special thanks are due to Mr. Famechon, the Director of the Travel Section of the French Ministry of Public Works and to his representative in London, Mr. Vignon, as well as to Mr. Dorand, the director of the Compagnie Française du Tourisme, and to Mr. Romain of that company, who undertook the personal management and supervision of the arrangements.

VISIT TO LORRAINE.

The party proceeding to Lorraine numbered just 100, and left Paris at 4 P.M. on Tuesday, September 6, arriving at Metz on the same evening.

VISIT TO HAYANGE.

On Wednesday, September 7, motor cars supplied by the Autavia Company of Metz were in attendance at the various hotels at 8 A.M., and the whole party was conveyed to Hayange, where

it was met by Mr. François de Wendel, and a considerable number of members of his staff, including Mr. Delarge, the general manager of the works.

The members were conducted to the works of Les Petits-Fils de François de Wendel & Cie., where they first inspected the ore and coke bins and the blast-furnace charging installation. The visitors then passed on to the blast-furnaces, one of which was in process of being tapped. The metal is run direct into 15-ton bogie ladles, and is transported to the mixers at the steelworks about $3\frac{1}{2}$ miles away. Both the Halberg-Beth dry-cleaning system and the ordinary wet-cleaning system for the furnace gas are installed. When the dry system is in operation the clean gas is used for the hot-blast stoves and for the gas-engines, whereas when using the wet-cleaning plant the gas for the stoves receives only the primary cleaning, while that for the engines is further cleaned and dried. Practically the whole of the power used in the works is electrical, the electricity being generated by blast-furnace gas-driven engines.

The Hayange works consist of two groups of blast-furnaces : four at Hayange (two of 200 tons and two of 150 tons). These latter will be replaced by two new 200-ton furnaces. There are six blast-furnaces at Paturel (two of 180 tons and four of 225 tons). The basic plant, built in 1880, consists of six converters. These works were the first in Lorraine to adopt the Thomas-Gilchrist process. There are two blooming-mills and five stands for rolling rails, girders, and sleepers. The open-hearth plant (built 1903 to 1910) consists of four 60-ton furnaces, with a fifth under construction. Plate and sheet mills are attached to this department with a galvanising shop close by, and wagon-building shops. The rolling of large I-girders in the three-high mill was witnessed and opportunity was also given to inspect the other departments.

The Hayange works have been the property of the de Wendel family since 1704. Henri de Wendel was the first on the Continent to introduce at his works the Thomas-Gilchrist process, which shortly afterwards led to the vast development in the use of the Minette ores of Lorraine and Luxemburg. During the war the property was sequestered and administered by the Germans, who in 1918 had ordered the liquidation of the company in favour of a German syndicate, these proceedings of course being rendered void shortly afterwards by the signing of the Armistice.

Some miles away are the Moyeuvre works (eight blast-furnaces, four basic Bessemer converters, and rod and bar mills).

The company derives its ore from mines in the vicinity and from Briey. It also owns collieries at Petite-Rosselle and at Hamm in Westphalia. In 1913 the works produced 847,000 tons of pig iron and 773,000 tons of steel.

On leaving the steelworks the party was conveyed in automobiles to some neighbouring mining works belonging to the company to witness a demonstration of the use of liquid air as an explosive in mining operations. Members were shown a gallery which had been excavated in a hillside for a length of $2\frac{1}{2}$ miles, the tunnelling work having been performed entirely by means of liquid air cartridges. The advantages of the system consist not only in the removal of a greater amount of material in a given time per man employed, but the gallery can be safely entered thirty seconds after the explosion, whereas using ordinary explosives it was necessary sometimes to wait as much as eight hours before the atmosphere was clear. Near the entrance to the gallery were laboratories for experimental work on liquid air, and some pretty and interesting experiments were made for the benefit of members, including the freezing of grapes, tomatoes, and rubber tubing.

THE JOEUF AND MESSEMPRE WORKS OF MESSRS. DE WENDEL.

The members then resumed their seats in the automobiles and travelled by a winding road through the wooded hills to Monsieur François de Wendel's chateau at Joeuf, where they were most hospitably entertained to luncheon by their kind hosts. The guests were received by Mr. François de Wendel and Mr. and Mrs. Guy de Wendel. After the luncheon Mr. F. de Wendel proposed the toast of the Institute and Mr. Iltyd Williams, Hon. Treasurer, responded. The members then proceeded to visit, under the guidance of their hosts and of Mr. Bosment, the general manager, the works at Joeuf, which were built by Messrs. de Wendel and Schneider after the separation of Hayange and Moyeuvre from France in 1871. They were primarily constructed for rolling rails, and at the end of 1913 they consisted of three blast-furnaces, six basic converters, and four rolling-mills,

including a wire rod rolling-mill plant. The works were very largely pillaged or destroyed during the war. Near the entrance to the offices the heavy cast iron drop-weight used by the Germans for breaking up machinery had been mounted on a pedestal. The drop-weight had been specially made for the purpose, and bore the name "Fritz" cast in relief near its upper edge.

Four blast-furnaces have already been rebuilt and blown in, and the others will be ready very shortly. The steelworks were restarted on June 8, 1920, and the blooming-mill was put to work on the same day. The wire mill has been entirely rebuilt, and started on October 25, 1920. The rail and billet mill and the new three-high 600 millimetre mill are ready to begin operations.

FORGES ACIÉRIES DE LA MARINE D'HOMÉCOURT.

During the same afternoon the works at Homécourt were visited, being received by Mr. Dufrenois, the general manager, and a number of the members of his staff. Here the work of reconstruction has not yet made great progress. The seven blast-furnaces were practically destroyed during the war, together with the hot-blast stoves. The gas-engines, generators, and rolling-mill engines were bodily removed, and the steelworks, containing four 17-ton converters and the rolling-mill building, had been completely destroyed by dynamite, the foundations having been blown up and the superstructures brought down. Nevertheless, the company has succeeded in restarting two of the blast-furnaces, and the steelworks and mills are in process of rebuilding. The reconstruction scheme includes the laying down of a large blooming-mill, a Morgan billet-mill, and a universal mill for large plates up to 1200 millimetres.

THE IRON ORE MINES OF DROITAUMONT.

A few more miles in the automobiles brought the party to the Mines de Droitaumont, which are the property of Messrs. Schneider & Cie., and are situated in that district of the Lorraine ore-field known as the Orne.

The members were welcomed by Mr. G. Leickmann, and a

telegram conveying the greetings of Mr. Eugène Schneider and his regret at his inability to be present was also received.

The depth of the shaft is about 210 metres. There are three seams—the red, the grey, and the brown—the grey seam being the only one actually worked. It is freely calcareous and contains 34 to 40 per cent. of iron. The output in 1913 was 404,687 tons, and at the present time the extraction is at the rate of 190,000 tons. Due to careless mining on the part of the Germans during the time of their occupation, the inrush of water is much greater now than in 1913, and it is necessary now to pump 4·5 as against 3 cubic metres of water per minute formerly. The damage to the mine during the war amounted to 12 million francs.

The party inspected the plant and a number of visitors descended the shaft. Refreshments were served at the conclusion of the visit and the return journey to Metz was then made. The route taken was over the battlefield of Gravelotte, where the graves of those who fell in 1870–71 were seen, still carefully preserved in the fields and by the roadsides.

HAGONDANGE WORKS.

On Thursday, September 8, the automobiles were again in attendance at the hotels, and conveyed the members to Hagondange, which was reached about 10.15 A.M. The works, built by Thyssen between 1911 and 1914, were acquired after the war by the Union of Consumers of Metallurgical Products and Industries, and they may be classed as among the most modern and best laid out in Europe. The works cover over 1250 acres and consist of six 300-ton blast-furnaces, five 30-ton converters, one 80-ton and one 60-ton tilting-furnace, and three electric furnaces. The annual capacity of these works is 600,000 tons of steel, and the number of workmen employed is 6000. The whole of the gases from the blast-furnaces are cleaned and used to provide energy for the works. The company own nearly 14,000 acres of iron ore concessions in Lorraine, with an annual productive capacity of one and a half million tons, and near the works is a well-built and picturesque garden city, in which most of the 6000 workmen employed are housed. The members were

welcomed by Mr. Orfila, the general manager, and were taken over the works, visiting the blast-furnaces and the rolling-mills.

THE ROMBAS WORKS.

The party on the conclusion of the visit were driven to Rombas, where the members were entertained at luncheon by invitation of the Rombas Company. In the absence of Mr. Th. Laurent, the managing director of the company, Baron Reille, presided, being supported by Mr. Hemmer, the general manager, and Mr. Jaques Laurent. The luncheon took place in the Casino of the Rombas works, an extremely handsome and commodious building, which serves as a club for the recreation of the staff. Baron Reille extended a cordial welcome to the members, on behalf of whom Professor Henry Louis, Member of Council, responded.

After luncheon the members proceeded to the Rombas works, which were founded in 1888 by a German company, but were liquidated in 1919 and purchased by the newly formed Société Lorraine des Aciéries de Rombas for 125 million francs. The works consist of eight blast-furnaces, eleven gas-driven blowing-engines, six converters, and a large and powerful rolling-mill installation. Four of the blast-furnaces have vertical hoists, three are charged by means of skips, and one is served by an inclined hoist with self-tipping car.

On the conclusion of the visit, about 5 p.m., the party divided, eighteen of the members travelling to Luxemburg under the care of Mr. Henri Coqueugnot and Mr. A. Kipgen, while seventy-five proceeded direct to Nancy by the cars of the Autavia Company, reaching that city about 8 p.m. Mention should be made of the admirable manner in which the Autavia Company carried out its contract with the Institute, and the care taken by Mr. Maret, who superintended the details of the arrangements on behalf of the company.

BLAST-FURNACES AND FOUNDRIES OF PONT-À-MOUSSE.

On Friday, September 9, an early start was made from Nancy in automobiles to inspect the works of the Société Anonyme des Hauts Fourneaux de Pont-à-Mousson. Throughout the war

Pont-à-Mousson lay within range of the enemy's guns and was almost entirely destroyed by shell fire. Altogether 5000 projectiles fell within the area occupied by the factory, every building being laid in ruins, but some of the machinery, including the gas-engines, had been to some extent protected by sand-bagging. The original foundry was built in 1856. In 1880 the company, under the management of Mr. Camille Cavallier, who is still at its head, was well established, and its record was one of rapid progress. At the time the war broke out it was producing 285,000 tons of pig iron, 190,000 tons of castings, and about 137,000 tons of cast-iron pipes annually, and the company had a large export trade in pipes, which were its chief speciality.

The party was welcomed by Mr. Camille Cavallier, the chairman of the company, Mr. Marcel Paul, director, and Mr. Mouchette, the works manager, and was conducted over the works. The visitors were greatly impressed here as elsewhere by the remarkable energy shown by the French ironmasters in repairing the ravages of war, and the rapidity with which they had reconstructed the more important parts of the works. The blast-furnaces and foundries were inspected, where a considerable amount of work was already in progress. The company owns another blast-furnace plant and an iron ore mine at Auboué, which, however, had been in German hands throughout the war and had been completely despoiled, the whole of the stock of ore and pig iron carried off, and about three million tons of ore had been mined with every circumstance of waste and neglect of precaution. After passing through the works a visit was made to the battlefields in the Bois-le-Prêtre, the wooded hills which command the town. These woods were the scene of some of the most stubborn trench fighting of the war. In the early days the Germans occupied the town, but within a short time they were ejected from it, and for four years they and the French remained entrenched at a distance of about 15 metres from each other in the woods. After August 1915 the heavy fighting died down, and the combatants faced one another with occasional raids until September 1918, when the Americans, following up their attack at St. Mihiel, drove the Germans out. The party was conducted through the woods, where the network of old trenches is still to be seen, half overgrown with all the litter of the battlefield still remaining.

On the flat top of the hill nothing remains of the trees but splintered stumps, and at the summit is the Croix des Carnes, where a monument is in process of erection. The party gathered round the pedestal of concrete, and one of the hosts, Colonel Plassiart, who had served throughout the war, gave the members an account of the struggle, of which a translation was afterwards given by Mr. A. S. Pye-Smith.

The party then descended the hill and again repaired in the automobiles back to the works. Luncheon was served in the handsome recreation hall adjoining the factory. Mr. Cavallier presided and cordially welcomed the members in a brief speech. At the conclusion of the luncheon Mr. Marcel Paul addressed the guests, referring to the difficulties under which the French iron industry was labouring, owing to the lack of means for the completion of their reconstructive work, and to the dangers which he feared still lay ahead of them in the future. Mr. J. Payton, President of the Staffordshire Iron and Steel Institute and honorary member of the Council, replied, thanking the kind hosts for their welcome, and expressing the appreciation of the members of their sense of the extreme difficulties in which their colleagues of the French iron industry were placed. The party then broke up and proceeded to the station at Pont-à-Mousson, whence it proceeded by special train for Paris.

CREUSOT, LYONS, AND ST. CHAMOND EXCURSIONS.

The members who had selected this excursion left Paris after luncheon on Tuesday, September 6, by the 2.10 express from the Gare de Lyon. Three special carriages, a special restaurant car, and a luggage van were attached to this train for the accommodation of the party, which included several ladies, and consisted on the outward journey of seventy-five persons. Dinner was served before reaching Chalon-sur-Saône, at which the train was timed to arrive at 8.49 P.M.

VISIT TO CREUSOT.

On arrival at Chalon the party was met at the station by Mr. de Sezille, accompanied by Mr. Litzellmann, from the Paris

offices of the firm, and several members of the staff of Messrs. Schneider's works at Creusot, and was divided into two groups, one of which was conveyed from Chalon to Creusot in special motor vehicles kindly provided by Messrs. Schneider, while the remainder of the party was provided with hotel accommodation in Chalon itself.

The drive to Creusot from Chalon occupied rather less than an hour, and on arrival at Creusot the members were taken to the Château de la Verrerie, where they were most hospitably received and entertained by Mr. and Mrs. Schneider. La Verrerie is Mr. Schneider's private residence, and occupies an eminence overlooking the works on one side, and on the other commanding extensive views of the park and surrounding country. It is built on the site of an ancient glass-works, from which it derives its name, and is one of the most extensive and magnificent residences in France. In the courtyard are preserved two interesting relics of its former purpose—a pair of glass kilns resembling the pottery kilns familiar to residents in North Staffordshire. One of these kilns has been converted into a private oratory, and the other into a miniature theatre. The party stayed the night at La Verrerie as the guests of their kindly hosts, no pains being spared by the latter to render their visit as comfortable and enjoyable as possible.

The remainder of the party, which had remained in Chalon, was distributed amongst various hotels in that town. This task was most admirably achieved by Mr. Tribout, a member of the staff of Messrs. Schneider's works at Chalon, in circumstances of some difficulty and complication, one of the hotels at which members were to have been accommodated having at the last moment repudiated its undertaking. Mr. Tribout had, therefore, to improvise fresh arrangements and to distribute those displaced at other hotels, a task he discharged with great ability, and for which the members in question were greatly indebted to him.

Those staying at Chalon were under the necessity of making an unusually early start on the following morning, when a special train, kindly provided by Mr. Schneider, left Chalon station at 7.20 A.M. to take them to Creusot. Here they were met by officials from the works, by whom they, together with the guests

of Mr. Schneider at La Verrerie, were conducted to the works. After visiting the older portions of the Creusot works, the members were entertained at luncheon in the tennis court by Mr. Schneider, who presided over an assembly of not far short of 200 guests. The toast of the guests and of the Iron and Steel Institute was proposed in a felicitous speech by Mr. Schneider, and was responded to by Mr. Francis Samuelson, President-Elect, who was supported by Sir Robert Hadfield, Bart., F.R.S., Past-President, and by Sir William Ellis, G.B.E., Vice-President.

At the conclusion of the luncheon the visits to the works were resumed, the members being taken by train to Breuil to view the splendidly equipped steelworks and rolling-mills.

As it was thought that a too-prolonged visit to these works might prove fatiguing to the ladies of the party, the latter were taken in automobiles to visit the welfare departments connected with the works, and were entertained at tea at the Orphanage, after having been conducted over the hospitals, schools, and clubs which Mr. Schneider has provided for his workpeople. The whole party was, on the conclusion of the visit, reconveyed by the special train to Chalon, where they arrived a few minutes before the Lyon express, to which had been attached the special carriages in which the journey from Paris to Chalon had been made.

The Creusot works, the cradle of the Schneider establishments, were founded by the grandfather of the present head of the firm, shortly after the close of the Napoleonic wars. They consist of blast-furnaces, steelworks, and very extensive forging, pressing, and locomotive shops (capacity 300 to 350 locomotives, of which the "Pacific" and "Mikado" types are the best known). There are also large turbine construction shops, with an annual capacity of 200,000 kilowatts.

The older works, which are situated at the foot of the hill on which the chateau of Mr. Eugène Schneider stands, are connected and practically continuous with the large new Breuil steelworks, which were laid down in 1914. They consist of eight open-hearth furnaces, six being of 50 to 60 tons capacity. Wellman-Seaver chargers are employed, and the gas-producer plant, which consists of two batteries, each of 14 Hilger pro-

ducers, is exceedingly interesting. The rolling-mill equipment is very complete, and has an annual capacity of 400,000 tons of blooms, 100,000 tons of billets, 60,000 tons of finished steel sections, and 70,000 tons of plates.

Adjoining these works are the Henri-Paul works, named after Mr. Schneider's eldest son, who was killed during the war.

The express left Chalon shortly before 8 P.M., and dinner was served on the train directly it had started. Lyons was reached at 10.20 P.M., whereupon the members were, immediately on arrival, taken in special vehicles to their hotels in Lyons, whither their luggage had preceded them earlier in the day. The arrangements were admirably carried out by Mr. R. Elsdon, the librarian of the Institute, and Mr. K. Blackmore, who, in a voluntary capacity, rendered the greatest services to the Institute, both in conjunction with Mr. Elsdon in Paris, and throughout the Creusot, Lyons, St. Chamond excursion.

VISIT TO ST. CHAMOND.

On the morning of Thursday, September 8, the members left the Perrache station, Lyons, by special train for St. Chamond, which was reached at 11.20 A.M. Here the members were met by Mr. Th. Laurent, the managing director of the Compagnie des Aciéries de la Marine et d'Homécourt, together with Mr. A. Guillaïn, one of the directors of the company, and a number of members of the staff of the works, by whom they were taken to the Château de Jarez, which is a handsome building standing in ornamental grounds close to the station of St. Chamond. Here the visitors were entertained at luncheon, Mr. and Mrs. Laurent being the hosts. On the conclusion of the repast Mr. Laurent proposed the toast of the visitors, and Mr. Samuelson, Sir Robert Hadfield, and Sir William Ellis replied briefly in French and proposed the toast of Mr. and Mrs. Laurent and of the company.

The members were then taken in automobiles to visit the works, which are situated at the further extremity of the town. Here they were shown the artillery workshops and fitting shops, and were given an interesting lecture illustrated with cinematographic views showing researches in metallurgy which had been

carried out in the extensive and well-equipped laboratories of the company. Tea and light refreshments were then served, after which the members returned in automobiles to the station and thence to Lyons, where they arrived at 6.40 P.M.

BANQUET AT LYONS TOWN HALL.

The party was met at Lyons station by a delegation of the Town Council and of the Committee of Lyons Fair. The delegation was headed by Mr. C. Cabaud and Mr. Rivoire, Vice-Presidents, to whom the principal members of the party were informally introduced, after which the delegation withdrew, and the members proceeded to their respective hotels.

The evening of Thursday, September 8, was devoted to a banquet at Lyons Town Hall, a magnificent building in the transitional Renaissance style, situated in the Place des Terreaux, where the members were the guests of the Town Council and the Committee of the Fair. The State apartments, which are amongst the most ornate and beautiful of any public building of the kind in Europe, were brilliantly illuminated, and the guests were received in the Grand Salon by Mr. Herriot, Mayor of Lyons, deputy for the Rhône and formerly Minister of Public Works, who was supported by Mr. Lignon, Chairman of the Lyons Fair Committee; Mr. Rivoire, Vice-President; Mr. Morel, Vice-President of the Lyons Chamber of Commerce; General Tillion, the Military Governor of Lyons, and many members of the Town Council and of the Committee of the Fair, including Mr. Victor, the manager.

After the reception a procession was formed and the way led to the banqueting-hall, where dinner was laid for about 200 guests. Mr. Herriot presided and welcomed the guests in a most interesting speech in which he outlined the objects of Lyons Fair, and eloquently pleaded the importance of such institutions in promoting good-will, understanding, and mutual forbearance between nations, and so furthering the cause of industrial progress and prosperity. Speeches were also made by Mr. Rivoire and General Tillion, after which Mr. Francis Samuelson expressed in French the warm appreciation of the visitors for the hospitality and kindness with which they had been received in Lyons and

cordially endorsed the sentiments voiced by the Mayor. Sir William Ellis, likewise speaking in French, proposed the toast of the City of Lyons and its Fair, which was supported by Sir Robert Hadfield and by Professor Le Chatelier, after which the repast terminated, and coffee and wines were served in the Salon. The whole function was one which was greatly enjoyed by those privileged to be present, while the warmth of the welcome extended, and the kindly hospitality evinced by the hosts, contributed to make the occasion one of the most memorable of the events of the meeting.

VISIT TO LYONS FAIR.

On the morning of Friday, September 9, the members assembled in the Place Verdun, the huge open space by the Gare Perrache, where, by the kindness of the Committee of Lyons Fair, carriages had been provided to take them for a drive round Lyons, to the Parc de la Tête d'Or, and to the Palais de la Foire, the wonderful range of permanent buildings in which the future fairs are to be held.

Lyons Fair is a very ancient institution, dating back to the commencement of the fifteenth century. It is held twice a year, in the early spring and in mid-autumn, and has hitherto been housed somewhat vicariously in wooden booths scattered amongst the principal squares of the city and along the quay. It is now proposed to house it permanently in a series of magnificent buildings on the boulevards bordering the park, on the banks of the Rhône, and within easy access of the centre of the city. It will consist of a great longitudinal transept 46 feet wide, having on each side of it thirty arcades, varying in length from 100 feet to 140 feet each, according to the exigencies of the site. These arcades are each to be 50 feet wide, the distance between each arcade being 38 feet. In the centre will be a great assembly hall, contained in an oval-shaped building 175 feet major diameter, while at one end there will be an immense dépôt and warehouse, and at the other there will be a large oblong exhibition hall for larger exhibits, such, for instance, as motor-cars, &c., 200 feet long. The total projected length of the buildings will thus be upwards of 900 yards, or over half a mile. The Palais is thus designed

eventually to comprise no less than 4800 stands, arranged on three floors, each stand measuring uniformly 14 feet by 12 feet, and as a holder may rent one or more adjacent stands, the partitions between them being removable, it will be seen that adequate space can be obtained for the exhibition not only of small articles, but of bulky merchandise, machine tools and machinery, light and power being supplied free.

Five of the buildings have already been completed, and the foundations laid for three more. They are handsomely built in structural steel and concrete, and are embellished with freestone ornaments and groups of statuary symbolic of the industries to which they are severally to be devoted, as it is the intention of the promoters eventually to sectionise the buildings for different industries. The scheme has thus advanced far beyond the stage of a project only, and is being rapidly pushed to completion by the energetic and devoted founders.

VISIT TO NORMANDY.

The group of members who had selected Normandy as the object of their visit, left Paris on the morning of Wednesday, September 7, at 8.45, by the ordinary express from the Gare St. Lazare to Caen, special carriages being attached to this train for the accommodation of the party. The luncheon was served on the train, and on arrival at Caen the party, which was accompanied by Mr. P. Gouge, the Secretary of the Société Normande de Métallurgie, was taken from the station in automobiles kindly provided by that company to the works. These are situated about four miles from the town, on an elevated plateau, the approach to which is through a well-wooded and picturesque countryside. On arrival the members were met by the managing director, Mr. Morette, and a number of the members of the staff of the company, and were taken over the works, where they visited the power-house, the blast-furnace and steel plant, and the rolling-mills, being subsequently taken to view the model village attached to the works in which the company houses its work-people, and the foremen and certain members of the staff. Much interest was shown in the coke-oven plant, the daily output of

which is 1760 tons of coke, the coal consumption being 2380 tons per day.

The Mondeville-Colombelles works of the Société la Normande de Métallurgie are about four miles from Caen, and consists of two large blast-furnaces of a daily capacity of 350 to 400 tons of pig iron, charged by means of a Munier vertical hoist. The details of the blast-furnace tops are exceedingly interesting. The ore used at the blast-furnaces comes from the extensive mines owned by the company at Soumont and elsewhere. The blast-furnace gases are cleaned by the Halberg-Beth process. The by-product recovery plant is very extensive. The steelworks comprises Hilger producers and Kerpely producers, and five 30-ton basic open-hearth furnaces, besides the Bessemer converter department with three 30-ton Bessemer converters of the Burbach type. The large new mills are all electrically driven, and the central power-station contains engines and generators capable of developing 54,000 horse-power.

On the conclusion of the visit the members were entertained at tea by the company, and returned to Caen by automobiles, which set them down at the Hôtel d'Angleterre, where accommodation had been provided. The evening was spent for the most part in exploring the city and its environs, and on the morning of Thursday the 8th the members proceeded to the private station of the Société Normande at Caen Basin, where they inspected the wharves of the company, which are equipped with an efficient installation of Priestman grabs for the rapid loading of ore on to the vessels in the docks. A special train was provided by the hospitality of the company, by means of which the visitors subsequently proceeded to the Soumont works, which are situated some eighteen miles from Caen, the journey being made on the private lines of the company. Here they visited the power-house, which is at present only partially equipped, but has been designed for a very large capacity. Further machinery will be added as the needs arise, and as the mine is further developed. The ore is brought from the mines by means of an electrically driven incline, and after being tipped into bunkers is fed to tip wagons and hauled up to the calcining kilns, which are for the most part of the modified Gjers type.

On their return to Caen the members were entertained at

luncheon by the company, Mr. Morette being in the Chair, and having on his right Lord Airedale, and on his left Mr. Chéron, Senator of Calvados, and Mr. Gérard, member of the Chamber of Deputies. After the usual loyal toasts, Mr. Morette proposed the health of the visitors, and reminded them that in Normandy the British were looked upon, not as foreigners, but as members of one family. Lord Airedale replied, and expressed the warm thanks of the visiting members for the kindness and hospitality they had received. At the conclusion of the repast the members repaired to the Town Hall, where the Mayor of Caen held a reception, and the remainder of the afternoon was devoted to visiting places of interest in Caen, including the Abbaye des Dames (in the church of which Matilda, the mother of King Stephen, is buried) and some of the interesting old buildings and hotels with which Caen abounds.

On the morning of Friday, September 9, automobiles, again kindly provided by the company, conveyed the members to Deauville, where they all lunched together at the Normandy Hotel. In the afternoon members were left to their own devices, and most of them availed themselves of the opportunity to visit the Casino and the town, after which they re-assembled at the Normandy Hotel and proceeded to the station, leaving at 8.7 p.m. for Paris. A special restaurant-car was attached to this train, and dinner was served en route, this function being prolonged far beyond its normal duration, and being made an opportunity to express on behalf of those present the warm appreciation of the valuable services which had been rendered in connection with the visit to Normandy by Mr. Gouge. The Council wish to take this opportunity of recording their thanks not only to that gentleman, but also to Mr. Roland Woods and to Mr. Dombrain, who accompanied the party and did much towards rendering the excursion a success.

VISIT TO LUXEMBURG.

The party which left Rombas for Luxemburg on Thursday afternoon arrived at that city after a comfortable drive, and were entertained at dinner at the Hôtel Brasseur by the Fédération des Industriels Luxembourgeois. Mr. Paul Wurth, President

of the Association, in a speech welcomed the guests and was seconded by Mr. A. Pescatore, Minister of Agriculture of the Grand Duchy, who acted at one time as its Consul in London, and was a well-known figure in Westminster. Professor Louis and Mr. Harbord replied on behalf of the guests.

SOCIÉTÉ METALLURGIQUE DES TERRES ROUGES AT ESCH.

On Friday morning the party was conveyed by automobile to the great works of Terres Rouges at Esch, formerly belonging to Gelsenkirchen, and now to Messrs. Schneider, where they were warmly welcomed by Mr. H. Coqueugnot, managing director.

There are six blast-furnaces arranged in pairs, the cooling of the boshes being effected by water blocks. For the gas the wet-cleaning system is employed, the final cleaning being done by Theisen washers. There are eight gas-driven blowing-engines of the Nürnberg type and ten gas-engine driven dynamos; two mixers of 100 tons capacity and two small gas-fired furnaces and one electric furnace for melting spiegel and ferro-manganese form part of the equipment of the converter plant. The electric furnace is apparently very successful for the melting of ferro and spiegel, which are added in liquid form to the metal in the ladle. At the conclusion of the visit the members were entertained to luncheon at the works Casino.

ACIÉRIES RÉUNIES BURBACH-EICH-DUDELANGE AT ESCH.

After lunch the party proceeded to visit the works of "ARBED" (Aciéries Réunies Burbach-Eich-Dudelange), where they were received by Mr. Barbanson, chairman of directors, and Mr. A. Kipgen, managing director.

The installation consists of blast-furnaces, converters, and rolling-mills, the equipment including a continuous mill for small sections, and bar iron and wire rolling. Attention was also directed to the mixers heated with tar oil and to the furnace for melting ferro-manganese by the company's own patent process. The use of blast-furnace gas for the heating of furnaces and the generation of power is a great feature in all these works.

DIFFERDANGE WORKS.

The members then proceeded to the Hadir works (Société des Hauts Fourneaux et Aciéries de Differdange St. Ingebert Rumelange), which specialises in the well-known broad-flanged I-beams, the flanges having parallel faces. The ingot is cast in the form of an I-beam, and after several passes through the blooming-mill it is rolled down in a Grey universal mill. The time taken to finish a 75-centimetre I-beam is about twenty minutes.

RODANGE WORKS.

After partaking of tea the members were conveyed to the Rodange works, where they were received by Mr. Fischer, the director, who showed them round the establishment. The blast-furnace charging installation presented several novel features, which greatly interested the visitors.

EMILE METZ INSTITUTE AT DOMMELDANGE.

On the return journey to Luxemburg the party halted at Dommeldange to inspect the Institute founded there as a memorial of the late Mr. Emile Metz. Mr. E. Mayrisch, President of the ARBED Company, received the guests and, accompanied by Mr. Kipgen and Mr. Biver, they were conducted through the workshops for the training of apprentices and other departments of the Institute. The curriculum includes courses in physical, theoretical, and applied sciences. The visitors were particularly interested in the psycho-physiological laboratory, where the methods of recording the physical development of pupils were demonstrated.

The party then returned to Luxemburg and took their departure the next morning for their various destinations.

OBITUARY.

EDWARD WINDSOR RICHARDS, an original member and Past-President, died on November 12, 1921, at his residence, Plas Llecha, Tredunnoch, Caerleon, Mon. Born in 1831, he was the son of the general manager of the Rhymney Iron Works. He was educated at Monmouth and Christ's Hospital, and commenced his mechanical engineering training in 1847 by serving his apprenticeship in the works of the Rhymney Iron Co. In 1854 he was appointed assistant engineer at the Tredegar Iron Works, and four years later he succeeded Mr. Josiah Richards as chief engineer, while, subsequently, in 1871, he became general manager of the Ebbw Vale Works, where the extensive Bessemer steel department was put down under his direction. He also designed and constructed a special blast-furnace at Ebbw Vale for the production of spiegeleisen. In 1875 he was appointed to succeed Mr. Edward Williams as general manager to Bolckow, Vaughan & Co., Middlesbrough. Here were erected at Eston in 1876, from his designs and under his supervision, the Cleveland Steel Works, including three hæmatite blast-furnaces, in which hæmatite pig iron was produced for use in acid converters, for the manufacture of Bessemer rails. At the time when Mr. Richards became manager of Bolckow, Vaughan's Works, the Cleveland iron ore deposits, which contain phosphorus, were practically neglected, as the methods of the day were inadequate for their development. Thomas and Gilchrist were, however, engaged upon their experiments, and had already succeeded in solving the problem of the use of phosphoric pig iron. The experiments at Dowlais were attentively followed by Mr. Richards, who, in association with the inventors, and with the late E. P. Martin, followed every stage of the process. Mr. Richards was, in fact, the first to prove the actual value of this process of manufacturing steel, and it is to his early efforts at the Cleveland Steel Works that the practical success of the process is generally ascribed. During the period 1888-1898 he was general manager of the Low Moor Iron Works. He was a member of the Institution of Civil Engineers and the Institution of Mechanical Engineers, being President of the latter body in 1896 and 1897. He was one of the founders of the Iron and Steel Institute, served on the Council since 1880, and was elected President for the years 1893 and 1894. He was a regular attendant at the meetings, and contributed to the discussions.

Sir GILBERT HENRY CLAUGHTON,^r Bart., Vice-President, died on June 27, 1921, at St. Briavel's Castle, Gloucestershire. He was the son of the Rt. Rev. T. L. Claughton, Bishop of St. Albans, and was

born in 1856. He was educated at Eton, and from there went to the works of Beyer, Peacock & Co., Ltd., of Manchester. At the age of twenty-eight he obtained an appointment at the Castle Mill Works at Tipton of the Earl of Dudley. He was eventually given the entire management of the whole of Lord Dudley's mineral estate, a position which he occupied with distinction for a period of twenty years. In 1905 he became a director of the London and North Western Railway, was appointed Deputy Chairman five years later, and in 1911 he succeeded Lord Stalybridge as Chairman. Among other activities, he was a member of the South Staffordshire Mines Drainage Commission, and of the Board of the Round Oak Works. He also served on the local Coal Trade and Iron Trade Wages Boards. He was created a baronet in 1912.

He was elected a member of the Iron and Steel Institute in 1886, a Member of Council in 1912, and a Vice-President in 1918.

Professor D. K. TSCHERNOFF, Honorary Vice-President, died on January 2, 1921, at Yalta in the Crimea. Professor Tschernoff was a pioneer in the science of the metallography of iron, and in him the representative of a whole period of Russian metallurgy and science passed away. His first publications were made in the early 'sixties, and his remarkable treatise on the critical points was presented to the Russian Technical Society in the same year—1868—that Mendeléeff published his investigations on the periodic law.

Dmitry K. Tschernoff was born in Petrograd on November 1, 1839. At nineteen years he graduated from the Institute of Technology, and continued his studies for a further three years in the faculty of mathematics at the Petrograd University. He was then appointed by that University as lecturer in mathematics, and in 1863 he returned to the Institute of Technology as assistant librarian, where he remained until 1866, when Oboukhoff offered him a post in his steelworks. During these years, from 1860 to 1866—partly spent in purely mathematical pursuits, and partly in classifying the important scientific and technical library—he gained by his studies the stupendous scientific insight which is typical of all his practical scientific works and researches. Osmond himself, twenty years later, wrote that in his opinion the whole subsequent development of physical chemistry lay in Professor Tschernoff's famous paper. The same insight is recognised in the dedication to Professor Tschernoff of the classical treatise on "Iron and Steel and other Alloys," by Henry Marion Howe.

The most important contribution made by Tschernoff to the metallurgy of steel is considered to be his treatise on critical points in steel, delivered to the Imperial Russian Technical Society in 1868, entitled "A Critical Survey of the Papers of Lavrow and Kalakoutzky on Steel and Steel Guns, and his Own (Tschernoff's) Researches thereon," *Proceedings of the Imperial Russian Technical Society*, 1868, pp. 399-400, and Discussion, April 20, May 2 and 11.

The manufacture of steel guns had started in Russia but ten years before. The processes were comparatively new, and there was no one of whom to ask advice. In other countries only Krupp had started manufacturing, but with the utmost secrecy. In Russia the Zlatoust plant, where the Anossov tradition was not quite extinct, was the only one in which steel foundry work was carried on, and even there only on a small scale. Under these conditions, every single operation—from the pouring of the liquid metal to the forging, and heat treatment processes—bristled with difficulties. It is easy to understand, therefore, that Lavrow and Kalakoutzky's researches on the liquation of steel and on the specific weights seemed to Tschernoff to warrant the most serious attention, and that he made these researches the object of the most far-reaching survey, intending to make the results widely known to all the prominent men connected with technical science and metallurgy. That Professor Tschernoff's researches would serve as a starting-point for a whole new branch of physical chemistry—metallography—no one was able to realise; and his audience did not agree with many of the statements it contained.

It was these researches that led to the determining of critical points and practical heat treatments, as, for instance, quenching in oil, the double heat treatment, the heat refinement, and many more, have all either developed out of Tschernoff's researches, or are the literal fulfilment of his precepts.

In 1878 Tschernoff read before the Russian Technical Society an important paper, "On the Structure of Cast Steel Ingots,"¹ in which he dwelt on such defects in steel castings as piping, blowholes, and segregation; simultaneously, he drew such a picture of the crystallisation of a steel ingot that his paper became a classic.

In 1889 Tschernoff was asked by the then Director of the Michael Artillery Academy, General Demianenkoff, to join the Professorial Staff of the Academy, and to occupy the Chair of Metallurgy and Metallography of Steel. Professor Tschernoff imparted his views with such lucidity and charm that the graduates as they left the Academy did so under the spell of his ideas and impulses, many of them with a profound and deep interest and affection for metallography and science in general.

Just as interestingly did Tschernoff expound his views on the use of the spectroscope in the Bessemer process; on the erosion of steel guns; on the surface tension; on strains and stresses during cold work (Lüders-Tschernoff lines); on the structure of crystals, and on the changes in that structure under the influence of heating.

The latter question especially absorbed his interest, and even in 1916, from Yalta, he sent a letter to the editor of the Russian Metallurgical Society's Journal, wherein he reviewed again the whole theory

¹ Published in the *Proceedings of the Imperial Russian Technical Society at Petrograd* in 1879, translated by W. Anderson and published in the *Proceedings of the Institution of Mechanical Engineers* in 1880.

of his point *b* and the relative question of the change in structure from crystalline to amorphous under the influence of heat.

Up to his last days Professor Tschernoff continued to sacrifice all his energies to science. He read papers on steel, he lectured in the technical institution, and he also worked on some of the mathematical problems arising on the tri-section of the right-angle.

This work he accomplished in exceedingly difficult surroundings, "without books, without necessary food, and even without warm clothing," hungry and starving, yet combining always with his work his dreams and his hopes for Russia, to whom he devoted all his life and all his genius.

Professor Tschernoff was elected a member of the Iron and Steel Institute in 1890, and was appointed by the Council an Honorary Vice-President in 1915.

[These notes have kindly been furnished by Colonel N. T. Belaiew, C.B.]

WALTER CROOKE died on March 23, 1921, at Priorlee House, near Wellington, Salop. He was engineering manager for the Lilleshall Company, Ltd., a position he had held since 1914. He had a very large and varied experience, particularly in the erection of iron and steel works plant, notably the supervision and starting up of the Cargo Fleet Works, Middlesbrough. Among the important positions he had held were those of general manager of the North Lincolnshire Iron Company, Ltd., chief engineer for the Frodingham Iron and Steel Company, Ltd., general manager of the Cargo Fleet Company, Ltd., and general manager of J. Summers & Co., Ltd. He was elected a member of the Iron and Steel Institute in 1893.

JOHN HENRY DEWHURST died on August 22, 1921, at his residence, Beechy Knowle, Richmond, Sheffield. He was born in Manchester in 1854, and received his engineering training with various firms in Sheffield and Manchester, and was subsequently engineer and chief engineer of various iron and steel companies down to 1891. In the latter year he joined his father's business, the firm being John Dewhurst & Son until 1902, when it was converted into a limited company. He was the designer and patentee of the "Dewhurst" system of slag ladles and cars and other steelworks plant. He was a member of the Institution of Mechanical Engineers, and was elected a member of the Iron and Steel Institute in 1903.

ALEXANDRE GOUVY died suddenly in January, 1921, at Leipzig, where he was engaged on the mission of recovering French plant which had been removed to Germany during the late war, and distributed at works in that country. By a strange coincidence his death occurred at the same hotel as that of his uncle, who, like himself, died suddenly twenty years before. Alexandre Gouvy was born in 1856 in Upper

Hombourg (Moselle), and was the son of Henry Gouvy, a descendant of a Walloon family, which had for many years been connected with the iron trade. He was educated at the École Centrale, and after completing his military service he obtained a post with the Austro-Hungarian Railway Company, with whom he remained for nine years, being engaged in the metallurgical section at the Resicza Works in Hungary, and becoming later manager of the Usines de Hutabankowa. In 1892 Gouvy became manager of the Alais Works at Tamaris, but three years later he became manager of the Ural mines of the Ural Volga Company in Russia and reconstructed the Awzianopetrewsk Works, on leaving which he established himself as a consulting engineer in Düsseldorf, and was responsible for the laying down of several rolling-mills, electric power-stations, and gas-cleaning plants. In 1906 he was for a time the manager of the Hughesovka Works after Reymond, the general manager, had been assassinated. It may be remembered that Reymond was shot while driving, and it is interesting to recall that Gouvy was seated by his side at the time. During the war he was appointed a member of the Technical Artillery Mission sent to Russia, and during 1917-1918 he was at the French Ministry of Munitions. After the Armistice he travelled for some time in the United States. He had had a distinguished metallurgical career, being a recognised authority on blast-furnace practice, gas-cleaning, and on rolling-mill operations. He was a frequent contributor to the *Bulletin de la Société des ingénieurs civils de France*, to the *Société de l'Industrie Minérale*, and to the Iron and Steel Institute, before which he read several papers. He was elected a member of the Institute in 1909, and made a member of the Legion of Honour in 1913.

PETRUS HÄRDEN died on August 2, 1921, in Stockholm, at the age of fifty-four. After gaining experience at several Swedish steelworks, he became in 1895 associated with Dr. Tholander, engineer of the Jernkontoret in the construction and equipment of steel furnaces. In 1909, in partnership with Dr. F. Kjellin, the inventor of the Kjellin electric furnace, he joined the firm Aktiebolaget Ingeniorsbyran Allians in Stockholm. On the decease of Dr. Kjellin in 1910 he became sole proprietor and managing director of the company, a position he held until his death. The company was specially engaged in the construction of ore-concentrating machinery. He was elected a member of the Iron and Steel Institute in 1908.

JAMES KEITH died on February 23, 1921, at his residence in London, at the age of seventy-two. He was the managing director of James Keith & Blackman Co., Ltd., engineers, of Arbroath and London. He served his apprenticeship in his father's works, and after visiting Canada and the United States he started in business on his own account, this business being subsequently amalgamated with that of the Blackman Ventilating Co., Ltd., in 1900. He was the inventor of

numerous hydraulic heating, ventilating, and other appliances, and amongst the earliest of these inventions was the apparatus for the manufacture of mineral oil gas. He was also the originator of the modern type of sectional boiler for hot-water heating.

He was an associate member of the Institution of Civil Engineers, a member of the Institution of Mechanical Engineers, and was elected a member of the Iron and Steel Institute in 1903.

FRANCIS ZACHARY LLOYD died on December 18, 1920, at Arley Hall, near Stourbridge, at the age of fifty-one. He was chairman and managing director of Weldless Steel Tubes (Ltd.), of Birmingham. For his services in connection with the organisation of supplies during the war, he was created a C.B.E. He was elected a member of the Iron and Steel Institute in 1920.

AMBROSE MONELL died on May 2, 1921, at Beacon, New York. He was born in New York in 1874, and after graduating from Columbia University in 1896 he became a metallurgical engineer to the Carnegie Steel Co., rising in six years to assistant to the president. At the time of his death he was an officer or director in each of the following: Air Reduction Co., American International Corporation, Coronet Phosphate Co., Haskell & Barker Car Co., International Motor Truck Co., and the International Nickel Co. His name is best known through its application to the alloy termed Monel metal, which was discovered during his presidency of the International Nickel Co., and has since been exploited by that company. While connected with the Carnegie Steel Co. he developed the process of open-hearth steel manufacture which bears his name. The process was adapted to the stationary open-hearth furnace. He was elected a member of the Iron and Steel Institute in 1900.

Colonel WILLIAM DAVID REES, of Swansea, died on August 20, 1921, at his London residence. He was an engineer, and carried on an important business in the county of Glamorgan. He commenced his career under the late R. D. Burnie at the Swansea Wagon Works, and later on, in conjunction with Mr. Kirby of Morriston, formed the firm of Rees & Kirby, constructional engineers. Afterwards he opened up business under the style of W. D. Rees & Co., consulting engineers, having offices at Swansea and London. He was elected a member of the Iron and Steel Institute in 1904.

JOSEPH WILLIAM RICHARDS, Professor of Metallurgy at Lehigh University, died at Bethlehem, Pennsylvania, on October 12, 1921. He was born in 1864 at Oldbury, England. He entered the United States at an early age, and was graduated from the Central High School of Philadelphia in 1882 with the degree of Bachelor of Arts. He entered Lehigh University in the same year, and graduated in 1886 with the

degree of Analytical Chemist, being awarded the degree of Master of Science in 1891, and that of Doctor of Philosophy in 1893. In 1887 he was appointed assistant instructor in metallurgy, and he served continuously from that time to his death, having been Professor of Metallurgy since 1903.

He was one of the foremost engineers of America, and had an international reputation in various branches of metallurgical technology. He served on numerous boards, and also as representative of American scientific societies at various International Congresses. He was one of the founders of the American Electrochemical Society; he became its first president, and since 1907 has acted as secretary. He took a prominent part in the publication of *Electrochemical Industry*, the forerunner of *Chemical and Metallurgical Engineering*. His important work on "Metallurgical Calculations" has become a standard work, and has a wide circulation in several languages. His other books include a treatise on aluminium and several translations, principal among which is Giolitti's work on "Cementation of Iron and Steel." He also contributed numerous papers to the technical press and scientific societies. He was a member of the Franklin Institute, and was elected a member of the Iron and Steel Institute in 1904.

J. PEARCE ROE died in London on September 2, 1921, at the age of sixty-nine. He commenced his career in his father's works at Cardiff. In 1870 he went to the Dowlais Iron Co., and was engaged under the late William Menelaus and Lewis Richards, first in the drawing office and subsequently as one of the general assistant engineers. In 1879, at the request of Mr. Menelaus, then chairman of the Orconera Iron Ore Company, he went to Bilbao, to install appliances for handling the ore. On completion of this work he was appointed resident engineer of the company, and in that capacity designed and carried out important work in connection with plant. In 1889 he commenced practice as a consulting engineer at Cardiff. In the following year he opened offices in London, and while devoting himself particularly to the development of the Roe system of ropeways for transporting materials, he eventually formed a company under the name of Ropeways Ltd., which was under his management and control, and has carried out a great number of important installations in all parts of the world. He was elected a member of the Iron and Steel Institute in 1889.

Sir THOMAS WRIGHTSON, Bart., died on June 18, 1921, at Neasham Hall, Darlington. He was chairman of the firm of Head, Wrightson & Co., Teesdale Iron Works, Thornaby-on-Tees, and for a time a director of the North Eastern Steel Co., Ltd., Middlesbrough. He was born in 1839 at Hangleton-le-Skerne, near Darlington, and received his education at private schools and at King's College, London. He selected engineering as a profession, and served an apprenticeship at the Elswick Works, Tyneside, of which his cousin, Sir William Arm-

strong (afterwards Lord Armstrong), was then the head. He also spent some time in civil engineering at Westminster with Sir John Fowler and Sir Benjamin Baker. In 1864 he went to the Teeside Ironworks, one of the largest bridge-building concerns in the country. He had a great deal to do with the building up the fortunes of this firm. Mr. C. A. Head, the senior partner, retired, but Sir Thomas remained the active spirit and chairman of the company until his death. The public life of Stockton and Thornaby-on-Tees for many years received his careful consideration; he was an active member of the Tees Conservancy Board, and held the position of chairman of the Works Committee of that body. He was also for a time chairman of the Stockton Chamber of Commerce. He was a Member of Parliament for Stockton from 1892 to 1895, and for East St. Pancras from 1899 to 1906. He was created a baronet in 1900. He was a member of the Institution of Civil Engineers, and of the Institution of Mechanical Engineers. He was elected a member of the Iron and Steel Institute in 1872, and has contributed the following papers to the Institute: "Patent Hydraulic Apparatus for Lowering Charges into Blast-Furnaces," 1872; "A New Form of Wagon Drop for Blast-Furnaces," 1874; "Some Physical Changes occurring in Iron and Steel at High Temperatures," 1879 and 1880; "A New Form of Centre Crane for Bessemer Plant," 1883; "The Application of Travelling Belts to the Shipment of Coal," 1897. He also frequently took part in the discussions.

SECTION II.

*NOTES ON THE
PROGRESS OF THE HOME AND FOREIGN
IRON AND STEEL INDUSTRIES.*

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In the preparation of these Notes the Editor has been assisted by L. P. SIDNEY,
Assistant Secretary, and others.

IRON ORES

AND OTHER METALLIFEROUS ORES USED IN THE IRON AND STEEL INDUSTRY.

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I.—GEOGRAPHICAL DISTRIBUTION OF ORES.

(Arranged in alphabetical order under Countries.)

Africa.—*Iron Ores of the South African Union* (Iron and Coal Trades Review, July 22, 1921, vol. 103, p. 100). Brief particulars are given of the character of the deposits in South Africa. Much of the information has been extracted from the reports of Stanley, Wagner, and Trevor. Titaniferous iron ore deposits occur around the edge of the Bushveld granite, which occupies an area of 200 by 70 miles, attaining the greatest development at Onderstepoort, nine miles north of Pretoria, and at Magnet Heights in Secocoeniland, where the quantity available is estimated at 24,000,000 tons at the surface. Chromite also occurs in the Bushveld granite, though not so extensively as the titaniferous ore. Deposits of magnetic iron ore occur at Pretoria and at Airlie Station in the Eastern Transvaal. Everywhere the ore is siliceous, containing silica from 24 to 35 per cent. and iron 41 to 48 per cent. On the Pretoria town-lands a bed of clayey ore occurs over a considerable area, and is of rather higher grade than the siliceous ore. In Natal, it is stated that three following kinds of ore occur in the district of Maritzburg: (1) Hydrated sesquioxide, which showed on analysis 62 per cent. of iron and 2·75 per cent silica. (2) Manganiferous hæmatite, showing iron, 50 per cent.; manganic oxide, 2·36; silica, 6·08; and phosphorus, 0·30. (3) Brown hæmatite containing iron, 35 per cent.; silica, 30·5; alumina, 10·30; phosphorus, 0·14. The only occurrence of ore in the Cape Province is in Griqualand West and Bechuanaland. No prospecting work has been done, but analyses of four samples showed 38·1, 53·0, 56·3, and 67·4 per cent. of iron.

H. Schneiderhöhn, *The Ore Deposits of the Otavi Range, South-West Africa* (Metall und Erz, May 22, June 8, 1921, vol. 18, pp.

225-236, 266-272). Surface explorations show that vanadium ores occur in some abundance. Small quantities of pure hæmatite and magnetite have also been discovered. The geological conditions of the country are described.

Australia.—*Iron Ore Deposits of Queensland* (Mining Magazine, April 1921). Particulars are given of the hæmatite ores of Mount Philp and Mount Leviathan in the Cloncurry district, and of the magnetite ore of Mount Biggenden. A Parliamentary Commission reported on these deposits in 1917 and recommended the erection of a small blast-furnace for smelting the Cloncurry hæmatites. Subsequent investigations led to a more extensive programme being undertaken, and works including blast-furnaces and steel plant are under construction at Bowen. There are about ten million tons of ore in sight at Mount Philp, and at least as much more covered by other formations.

At Mount Leviathan a large part of the hill, which is only about 270 feet high, consists of a lode of hæmatite estimated to contain about two million tons. The quantity of magnetite ore at Mount Biggenden is estimated at a minimum of 500,000 tons, with an average percentage of iron of 57·7 per cent. The composition of the hæmatite ores of Mount Philp and of Mount Leviathan are as follows :

	Mount Philp.		Mount Leviathan.	
	I.	II.	I.	II.
Iron	56·2	52·8	62·0	56·5
Silica	19·5	23·0	8·9	17·0
Phosphorus	0·023	0·03	0·11	0·08
Sulphur	0·010	0·01	0·04	0·05

Bolivia.—F. L. Hess, *Bolivian Tungsten Deposits* (Engineering and Mining Journal, September 24, 1921, vol. 112, pp. 492-499). The geology, ores, and methods of mining and milling at the Jorge Quinto, Ascencion, and San Antonio tungsten deposits are described.

Canada.—D. E. Woodbridge, *Iron Ore Deposits on the Belcher Islands* (Engineering and Mining Journal, August 13, 1921, vol. 112, pp. 251-254). Large deposits of iron ore have been discovered on the Belcher Islands in Hudson's Bay. The ores are said to be similar in character to those of Lake Superior, but owing to lack of communications and the climatic conditions, their development is at present impracticable.

A. H. A. Robinson, *Investigation of Iron Ore Deposits in Northern Ontario* (Canada Department of Mines, 1920, Summary Report No. 542). The deposits, mining operations, and output are described. The ore is high in titanium.

France.—*Iron Ore Deposits of Brittany* (Board of Trade Journal, July 21, 1921, vol. 107, p. 89). Brief particulars are given of the

deposits in this region, taken from a report published by the St. Nazaire Chamber of Commerce.

Germany.—*Molybdenum Ores in Upper Bavaria* (Bergbau, March 24, 1921, pp. 317–321). A short description is given of the wulfenite occurrences near Partenkirchen, with notes on the mining and preparation of the ores.

Hungary.—*The Manganese Ore Deposit near Urkut in Hungary* (Stahl und Eisen, August 11, 1921, vol. 41, pp. 1117–1118). In opening up a small coal-mine near Urkut, 25 kilometres north of the Plattensee in West Hungary, a manganese ore deposit of some importance was discovered in 1917. The ore is chiefly psilomelane, the larger lumps often being filled with pure pyrolusite crystals. The washed ore contains about 50 to 51 per cent. of manganese, and total resources of ore of this grade are estimated at about 400,000 tons. Three other secondary deposits have been found in the same neighbourhood, which lead to the belief that the total reserves may be considerably higher.

India.—*Quinquennial Review of the Mineral Production of India* (Records of the Geological Survey of India, 1921, vol. 52, 322 pp.). The report contains a detailed account of the minerals of India, together with information relating to production, consumption, imports and exports, and prices.

Jugo-Slavia.—E. M. Butler, *Mining and Iron Industries of Jugo-Slavia* (Department of Overseas Trade: Iron and Coal Trades Review, August 5, 1921, vol. 103, p. 168). The principal iron ore deposits are the mines of Ljubija and Vares, in Bosnia.

Mexico.—M. Rangel and A. Terrones, *Mineral Resources of Durango* (Engineering and Mining Journal, July 30, 1921, vol. 112, pp. 168–174). A survey is given of the mineral resources of Durango, Mexico, including a description of the iron ore deposits in Cerro del Mercado.

Norway.—E. O. Falkenberg, *Molybdenum Mines in Norway* (Teknisk Ukeblad, January 7, 1921, vol. 68; Engineering and Mining Journal, June 18, 1921, vol. 111, pp. 1021–1023). A description of the molybdenum mining industry in Norway, which underwent a great development during the war.

Peru.—C. P. Jimenez, *Review of the Development of the Mineral Industry of Peru in the last Hundred Years* (Revista Minera, October 6, 24, November 1, 1921, vol. 72, pp. 549–553, 568–569, 577–579). Statistics of the mineral industry are given from the beginning of the

nineteenth century. The ores of the base metals, except tin, exist in abundance, but one of the most important developments is that of vanadium minerals. Since the discovery of these in 1907 down to the end of 1920 the total amount of vanadium concentrates produced is 37,698 tons, with a content of 12,395 tons of vanadic acid. The total exports of tungsten have been 2487 tons of 62 to 74 per cent. concentrates, and of molybdenite $26\frac{3}{4}$ tons of concentrates containing $22\frac{1}{2}$ tons of pure molybdenite.

Vanadium Production in Peru (Boletin del Cuerpo de Ingenieros de Minas del Peru: Iron Age, August 18, 1921, vol. 108, p. 389). Particulars are given of the important vanadium deposits in Peru. The deposits are American controlled and operated and constitute the chief source of supply of vanadium in the world. The principal deposit, which is at Minasruga and is now the only one in active exploitation, has yielded since 1907 a total of 27,998 metric tons of concentrates.

Switzerland.—C. Schmidt, *The Jurassic Iron Ores of the Swiss Jura* (Schweizerische Bauzeitung, June 11, 18, 1921, pp. 277–279, 285–288). The possibility of developing the ore deposits of the Swiss Jura is discussed. H. Saemann (*Ibid.*, July 30, 1921, pp. 60–61) contributes some notes on the chemical character of the Fricktal ores.

United States.—G. H. Ashley, *Mineral Resources of Pennsylvania* (Proceedings of the Engineers' Society of Western Pennsylvania, 1921, vol. 37, pp. 1–20).

Iron Ore Resources of Europe.—M. Roesler, *The Iron Ore Resources of Europe* (United States Geological Survey, 1921, Bulletin No. 706). The author gives a summary of the facts concerning the deposits of iron ore in Europe and estimates of the reserves, based on the conclusions of other writers. The geological distribution of the deposits is considered, and the more extensive deposits are described. The economic value of the iron ore in the several countries of Europe is shown by tables and statistics of production and consumption.

Mineral Resources of the World.—F. L. MacCallum, *The World's Chief Deposits of Titaniferous Iron* (Iron and Steel of Canada, September 1921, vol. 4, pp. 222–225). The geographical distribution of titaniferous iron ore is dealt with.

O. R. Kuhn, *Manganese Ore Supply* (Iron Trade Review, August 18, 1921, vol. 69, pp. 425–429, 432). The distribution of the manganese ore deposits of the world is dealt with, and a table is given showing the typical analysis of manganese ore from the chief producing countries.

Manganese (Imperial Mineral Resources Bureau: The Mineral Industry of the British Empire and Foreign Countries, London, 1921, 151 pp.). The distribution of manganese ore in the chief producing 1921—ii.

countries is shown, together with statistics of production and average prices.

Tungsten (Imperial Mineral Resources Bureau: The Mineral Industry of the British Empire and Foreign Countries, London, 1921, 44 pp.). The report gives information regarding the distribution of tungsten deposits, statistics of production, and the chief uses of tungsten in industry.

E. Prost, *Distribution, Production, and Trade in Non-Ferrous Minerals and Metals: Vanadium* (Revue Universelle des Mines, July 15, 1921, vol. 10, pp. 153-156). The following vanadium minerals are enumerated:

Patronite, V_2S_5 ; carnotite, $K_2O \cdot 2U_2O_3 \cdot V_2O_5 \cdot 3H_2O$; roscoelite, $H_8K (MgFe) (AlV)_4 (SiO_3)_{12}$; vanadinite, $Pb_5Cl (VO_4)_3$; descloizite, $PbZn, Pb (OH) VO_4$; chileite (lead-copper vanadate); volborthite, $(CuCaBa)_3 (OH)_3 VO_4 \cdot 6H_2O$; mottramite (lead-copper vanadate), puchérîte ($Bi_2O_3V_2O_5$); sylvanite, $3Cu_2SV_2S_5$; hewettite, $CaO \cdot 3V_2O_5 \cdot 9H_2O$, and pascoite, $Ca_2VO \cdot 11H_2O$. The first named is the most important, and notes are given of its occurrence in Peru. The ash of Peruvian coals and of some Oklahoma coals contains appreciable amounts of vanadium, 50 per cent. of the ash of Yauli (Peru) coal consisting of Va_2O_5 . An Argentine coal from Mendoza contains 38 per cent. of vanadic oxide, but the coal itself is low in ash (0.63 per cent.). The fluctuations in price undergone in recent years by vanadium ores and ferro-vanadium are noted.

E. Prost, *Titanium Ores* (*Ibid.*, pp. 157-160), also notes the occurrence and production of ores containing titanium.

II.—MINING OF ORES.

Economics of Iron Ore Mining.—D. E. A. Charlton, *The Economic Situation of Iron Ore Mining in Latin America* (Engineering and Mining Journal, September 17, 1921, vol. 112, pp. 454-458). A short review is given of the economic prospects of an iron ore mining industry in Mexico, Cuba, Brazil, Chili, Colombia, Venezuela, Guiana, Uruguay, and Paraguay.

Methods of Mining.—R. H. Briggs, *Ironstone Mining in North Lincolnshire, England* (Canadian Mining Journal, June 17, 1921, vol. 42, pp. 480-482). Methods of mining the Frodingham iron ore bed are described.

L. Eaton, *The "Slushing" System in Iron Ore Mining* (Compressed Air Magazine: Iron and Coal Trades Review, June 17, 1921, vol. 102, p. 811). Slushing, as it is called, consists in so arranging the raises conveying ore to the main drifts and in so conducting mining that ore is brought to the raises by scrapers worked by small hoists employing

but one man. These scrapers are attached to the hoists by means of cables. Where this new system has been operated, hoists of two to three horse-power have been utilised, giving a rope speed of from 80 to 100 feet per minute and having a load capacity of from 1000 to 1500 lbs.

Iron Ore Handling.—G. Fagerberg, *The Transport Installations for Gellivara Iron Ore* (Jernkontorets Annaler, 1921, No. 6, pp. 245–274). The equipment of the stockyards, design of the ore wagons, and the automatic unloading arrangements are illustrated and described.

III.—PREPARATION OF ORES.

Sintering of Ore.—K. Endell, *Investigation of the Sintering Process* (Metall und Erz, 1921, vol. 18, pp. 163–167). Agglomerates for smelting from finely divided ores, flue dust, and other residues, if rendered porous and mechanically strong at 1000° C., require the minimum of fuel in the subsequent smelting process. Sintering of the mass is usually brought about by an increase in the grain size of the constituents with consequent intercrystallisation of the particles, in most cases accompanied by an increase in the specific gravity, or by reactions between the solid constituents of the mass resulting in an evolution of heat and partial fusion of the particles, or in the formation throughout the mass of interlocked crystals of a new compound.

Krom Sintering System (Iron Age, September 29, 1921, vol. 108, p. 794). The system employs a battery of circular cast iron pans. The bottom or grate portion of the pan is adapted to a cone-shaped sheet iron extension, from the apex of which the suction draught is drawn down. The retaining walls of the pan holding the charge on the grate form a motor-driven ram for pushing off the sintered material. The retaining wall is mounted on wheels and is provided with a cast steel plough, which travels clear of the grate and rips the sinter cleanly from the grate, at the same time breaking it into desirable sizes.

Concentration of Ore.—A Lhéraud, *Considerations in regard to the Mechanical Preparation of Ores* (Revue de l'Industrie Minérale, Mémoires, May 15, 1921, pp. 371–398). An account of the theory and practice of concentrating ores by washing and flotation methods.

REFRACTORY MATERIALS.

Graphite.—B. L. Miller, *Graphite Industry of the United States and Canada* (Engineering and Mining Journal, August 6, 1921, vol. 112, pp. 207–213). The geographical distribution, methods of milling, and marketing of graphite are described.

Zirconia.—H. E. Coley, *Zirconia in Relation to the Metal Industry* (Journal of the Birmingham Metallurgical Society, vol. 7, Part 14, pp. 560–574). The principal sources of zirconia ore and the preparation of zirconia refractories are dealt with.

Manufacture of Refractories.—W. J. Rees, *Notes on American Practice in Refractories* (Paper read before the Refractory Materials Section of the Ceramic Society, May 14, 1921). The chief sources of refractories used in the United States and the methods of their manufacture are described.

C. B. Stowe, *Making Refractories in America* (Iron Trade Review, May 12, 1921, vol. 68, pp. 1309–1311). The development in the manufacture of refractories in the United States is traced. The first fireclay brick was made in New Jersey in 1812.

Properties, Testing, and Uses of Refractories.—J. W. Mellor, *Plasticity of Clays* (Paper read before the Faraday Society, May 31, 1921). No method of measuring plasticity of clays is satisfactory which does not take account of the resistance they offer to change of shape and of the amount of deformation undergone without cracking. As water is added progressively to a dry clay the plasticity increases up to a maximum value, after which the further addition of water causes decreased plasticity. Clays gradually lose some of their so-called combined water at ordinary temperatures, but the water is regained on exposure to a moist atmosphere, showing that no change has occurred in the structure of the clay molecule.

A. Bigot, *Kaolins, Clays, and Bauxites* (Comptes Rendus, April 4, 1921). The changes in volume under the action of heat were studied. The variation in the length of briquettes was measured for each 100° C. rise in temperature up to the softening point of the material.

Edith M. Firth and W. E. S. Turner, *Shrinkage, Porosity, and other Properties of British Fireclays after being Fired at High Temperatures* (Journal of the Society of Glass Technology, October 1921, vol. 19, pp. 268–277).

A. S. E. Ackermann, *The Physical Properties of Clay* (Paper read before the Society of Engineers, May 2, 1921). Experimental results of a research on the fluidity and viscosity of clay.

L. Bradshaw and W. Emery, *Jointing Materials for Refractories* (Gas Journal, 1921, vol. 155, pp. 157-159). In a report of the Refractory Materials Research Committee to the Institution of Gas Engineers the authors describe experiments to determine the quality of mixtures for use as mortar in refractory brick work. Finely ground fireclay and silica brick were mixed in varying proportions, made into cones, and the refractoriness was determined in an electric furnace. The addition of a small amount of fireclay to silica brick produced a better effect than a small amount of silica brick added to fireclay. The eutectic mixture had the composition 15.01 per cent. Al_2O_3 , 80.3 per cent. SiO_2 , and softened at cone 19-20. The contraction, mechanical strength, and resistance to slag penetration increased with the fineness of grinding. The addition of grog reduced the contraction, but allowed a greater slag penetration. Fine clay with coarse grog had a greater contraction and crushing strength with less slag penetration in the mass than a mixture of coarse clay with fine grog.

L. Bradshaw and W. Emery, *Influence of Oxidising and Reducing Atmospheres on Refractory Materials* (Report of Refractory Materials Research Committee to Institution of Gas Engineers: Gas Journal, 1921, vol. 155, pp. 159-160). Pyrometric cones heated in an electric tube furnace and exposed to a current of coal-gas were found to remain erect at temperatures far above their normal softening points. On examination they were found to consist only of a hollow shell with a quantity of slag discharge at the base, or of a semi-vitrified mass covered with an infusible skin. The outer shell was extremely refractory, which appeared to be due to the formation of a thin film of hard carbon in intimate contact with the surface of the cone by the decomposition of the methane. Methane decomposes slowly between 800° and 1000°C . and more rapidly above 1000° , when in contact with hot surfaces. Above 950°C . it was possible to produce with certainty a firm refractory shell.

O. Rebuffat, *Dinas Bricks of Constant Volume* (Paper read before Refractory Material Section of the Ceramic Society, May 14, 1921). The disintegrating expansion of silica bricks results from the transformation of the quartz into tridymite, cristobalite, or fused silica, all of which have a much smaller specific gravity than quartz. In all silica bricks a small quantity of calcium silicate is formed during the firing, and this serves as a binder for the silica grains, but the quantity is too small by itself to facilitate the conversion of quartz into tridymite. Quartzites, which give products of constant volume, must contain some other substance, which, along with the calcium silicate, forms the flux by whose aid the change is produced. Experiments tend to prove that the transformation of quartz into allotropic forms of much lower density is facilitated by the presence of small quantities

of phosphoric acid, and in view of the wide distribution of phosphoric acid in rocks, it may be safely asserted that, if certain quartzites have the property of giving bricks of constant volume, it is due to the presence of small quantities of this substance in them. Microscopic examination of all the author's preparations showed that the allotropic varieties of silica formed under these conditions consisted mainly of tridymite. If the heating is prolonged for more than eight hours, the tridymite structure becomes more and more uniform, while the rare bi-refrangent grains that were first noted entirely disappear.

H. S. Houldsworth and J. W. Cobb, *Reversible Thermal Expansion of Silica* (Paper read before the Ceramic Society, October 6, 1921; Foundry Trade Journal, October 13, 1921, vol. 24, pp. 296-298). The results are given of an investigation of the thermal expansion of silica bricks after use in coke-ovens and steel plant. The reversible linear expansions of raw silica and silica bricks are discussed.

M. L. Hartmann and W. A. Koehler, *Physical Characteristics of Specialised Refractories* (Paper read before the American Electrochemical Society, September 1921). This paper is the fourth of a series on the physical properties of refractory materials, and describes a number of tests made to determine the transverse breaking strength of each of ten refractories at 20° and 1350° C. Within this temperature range chrome brick showed the most decided drop in modulus of rupture, followed in order by bauxite, magnesia, fireclay, and silica. Two bonded carborundum refractories showed an increase indicating that a decrease in their cross-breaking strength must occur at some higher temperature than 1350° C.

V. Bodin, *Resistance Tests on Refractory Products under Load at Different Temperatures* (Paper read before Refractory Materials Section of the Ceramic Society, May 14, 1921). The disparity between the softening and fusion temperature varies within very wide limits, being very considerable in the case of bauxite, more so for magnesia, and much less so for silica products. Curves are given showing the crushing strength in kilogrammes per square centimetre for each product as a function of the temperature to 1500° C. The majority of refractory products, particularly all the silico-aluminous, aluminous and silica products, show a tendency to decreased resistance to load on heating, the minimum being generally about 800° C. The same products on further heating exhibit a rapidly increasing resistance, with a maximum usually at about 1000° C. For certain clays this maximum may reach and even exceed four times the minimum. With a still further rise in temperature, a progressive decline in resistance, tending towards zero at about 1600° C., is observed with all refractory products. In general, all refractory products tend to become plastic or semi-plastic beyond about 1200° C.

E. Rengade and E. Desvignes, *Apparatus for Determining the Hardness of Refractory Materials at High Temperature* (Comptes Rendus, 1921, vol. 173, pp. 134-137). Ludwik's modification of the method

of Le Chatelier and Bogitch is used, a cone of Acheson graphite being employed for making an imprint in the material, and an electric furnace for heating. Clay bricks and a bauxite brick showed a progressive softening as the temperature rose. Silica bricks withstand penetration by the cone up to $1600^{\circ}\text{C}.$, beyond which point the adhesion of the grains suddenly breaks down and the cone penetrates, cracking the brick.

E. Lux, *Preparation of High-Grade Silica Bricks from Quartzite Rock* (Stahl und Eisen, 1921, vol. 41, pp. 258-264). Silica bricks made from quartzite rock show under the microscope a high degree of transformation even of the large quartzite grains. This transformation is effected by the use of a high burning temperature such as is employed in America. German silica bricks do not usually show such a high degree of transformation, but microscopical examination of the better class of bricks shows that by using a suitable method of manufacture a brick may be made from quartzite rock which is not inferior to those prepared from tertiary rock.

P. Rosin, *Factors affecting the Heat Losses in Metallurgical Furnaces* (Metall und Erz, January 22, February 22, March 8, 1921, vol. 18, pp. 37-45, 78-88, 99-104). The author attempts to derive a heat conductivity factor for furnaces constructed with different kinds of materials. Many conditions, however, which cannot be calculated affect the factor. The heat conductivity factors for the acid material and the basic material used for lining an acid Bessemer and a basic Bessemer converter were in the ratio of 1 to 4, but the difference between the maximum temperatures when blowing was not more than $29^{\circ}\text{C}.$ A table is given showing the composition, specific weight, porosity, and heat conductivity factor of the refractory materials in general use.

H. H. Middleton, *Silica Bricks for Coke-Ovens* (Paper read before the Coke-Oven Managers' Association: Colliery Guardian, October 28, 1921, vol. 122, pp. 1203-1204). The advantages of using silica brick in place of quartzite for the construction of coke-oven walls are discussed, and the results obtained at American coke-oven plants with ovens built of this material are given.

FUEL.

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I.—CALORIFIC VALUE.

Efficient Use of Coal.—E. V. Evans, *Chemistry of Combustion* (Paper read before the Institution of Mechanical Engineers, June 30, 1921). The author advocates the abandonment of the use of raw coal for the generation of heat for two reasons, namely, the highly complex nature of the reactions taking place during combustion, and loss of raw material which result. The physical and chemical reactions attending combustion are reviewed.

Sir George Beilby, *Fuel Problems of the Future* (James Forrest Lecture before the Institution of Civil Engineers, June 28, 1921: Iron and Coal Trades Review, July 1, 1921, vol. 103, pp. 1-2). The author emphasises the need for the more efficient use of fuel, which is absolutely necessary if a higher price is to be paid for coal. The annual output of coal in the United Kingdom is approximately 287 million tons, of which 60 million tons is consumed in factories, 31 million tons by the iron and steel industry, 15 million tons by railways, and 35 million tons for domestic purposes. About 139 million tons is burned in the raw or natural state of the coal, and the greatest of the fuel problems of the future is to decide what proportion of this total it will pay to subject to a preliminary operation of carbonisation or gasification, with the object of sorting out the potential thermal units of the coal into groups of higher availability or greater convenience as fuels, namely, gas, motor spirit, fuel oils, and coke.

F. E. Leahy, *Fuel Requirements of Steel Mills Analysed* (Paper read before the Association of Iron and Steel Electrical Engineers: Iron Age, September 29, 1921, vol. 108, pp. 811-813). The different kinds of fuel used in iron and steel works are enumerated, and their application briefly described.

Classification of Coal.—W. J. Wybergh, *Grading and Classification of Coal* (South African Journal of Industries: Iron and Coal Trades

Review, July 8, 1921, vol. 103, p. 36). The need for a more exact classification is pointed out, and the principal systems hitherto proposed are briefly described.

Substitutes for Coal.—E. Damour, *Substitutes for Coal* (Chimie et Industrie, 1921, vol. 5, pp. 11-17). The use of wood, peat, and lignite as a substitute for coal is discussed. The great drawback is their high moisture content.

Calorific Value of Coal.—F. S. Sinnatt and May B. Craven, *The Determination of the Calorific Value of Coal* (Bulletin of the Lancashire and Cheshire Coal Research Association, 1921, Bulletin No. 10).

Fuel Value of Brown-Coal.—W. A. Bone, *Researches upon Brown-Coals and Lignites* (Proceedings of the Royal Society, June 1921, Series A, vol. 99, pp. 236-251). The four principal classes into which coals may be divided are: sub-bituminous, including brown-coals and lignites; bituminous; semi-bituminous; and anthracite. The first is of more recent origin than the other three, and the coal in this class forms about 40·5 per cent. of the total world's estimated reserves, but owing to its low carbon content and high percentage of water its calorific value is much lower than that of the older coals. Its inferiority is to some extent compensated by its yield of valuable by-products. Investigations were made on Morwell brown-coal from Victoria, and lignites from Valdarno and Umbria in Italy, from Canada, and from Burmah. There were found certain definite temperatures, usually between 300° and 400° C., at which dry heating expelled considerable steam and condensed the cellulosic or humic contents, but no change took place in either hydrogen or hydrocarbons. The potential energy of the fuel may thus be concentrated by treatment, and such treatment constitutes a means of "up-grading" and improving these coals.

M. Dolch, *Prospects for the Extended Utilisation of Lignitic Brown-Coal* (Montanistische Rundschau, May 1, 16, June 1, 16, July 1, 16, 1921, vol. 13, pp. 170-173, 185-189, 206-208, 228-231, 249-254, 267-269). The article describes in general the processes for raising the calorific value, the briquetting of the raw coal, the complete gasification of lignite, the semi-coking of the coal, and trials with the various forms of the prepared fuel. The semi-coking process and its product yield the most economical results in any scheme for the utilisation of brown-coal.

Pulverised Coal.—H. Kreisinger and J. Blizard, *Fineness and Dryness of Pulverised Coal as Fuel* (Méchanical Engineering, May 1921, vol. 43, pp. 321-322, 326). From a series of extended tests it is concluded that the grinding and drying of the coal need not be carried

to such a high degree as has been thought necessary. It has been customary to grind to such fineness that 95 per cent. will pass through a 100-mesh screen and 85 per cent. through a 200-mesh screen. Results from coal of which 88·6 to 93·2 per cent. passed the 100-mesh and 64 to 74 per cent. the 200-mesh screen have been entirely satisfactory. Tests with undried coal showed equally good combustion as with coal dried to 1 per cent. of moisture. The best results are obtained when the powdered coal is burned at the rate of 1 to 1·5 lb. per cubic foot of combustion space per hour.

G. Bulle, *Applicability of Coal-Dust Firing in Ironworks* (Stahl und Eisen, July 21, 1921, vol. 41, pp. 985-994). The arguments in favour of and against the adoption of coal-dust firing for metallurgical furnaces are presented. In the case of ordinary open-hearth furnaces, it is calculated that an economy of about 40 per cent. may be obtained with coal-dust firing as compared with producer-gas firing.

J. F. Shadgen, *Explosion Hazard and its Prevention* (Iron Age, July 21, 28, 1921, vol. 108, pp. 127-130, 204-206, 239-240). The author deals with the characteristics of fuels, and the formation of explosive mixtures, with special reference to powdered coal installations.

R. James, *Powdered Fuel* (Proceedings of the South Wales Institute of Engineers, 1921, vol. 38, pp. 75-110). The preparation, handling, and the systems of firing pulverised fuel are described.

Uses of Powdered Anthracite and Recovery and Use of River Coal (Journal of the Engineers' Club of Philadelphia, February 1921, vol. 38, pp. 39-63). A series of papers by geological and mining authorities and engineers is published on the best methods of pulverising anthracite coal, together with results of boiler-firing trials made at the pulverised fuel plant at Lykens, Pennsylvania.

C. Longenecker, *Economical Firing of Steel Plant Boilers* (Blast-Furnace and Steel Plant, May 1921, vol. 9, pp. 308-310, 336). The author compares the methods of boiler firing and gives the result of a test on a 520 horse-power boiler fired by powdered coal.

C. Longenecker, *Present Status of Powdered Coal* (Blast-Furnace and Steel Plant, June 1921, vol. 9, pp. 394-397). The use of powdered coal under boilers is dealt with, and the results are given of tests obtained in burning different grades of coal.

F. J. Crolius, *Pulverised Firing in Steam Generation* (Blast-Furnace and Steel Plant, July 1921, vol. 9, pp. 453-460).

Report of the French Commission on the Utilisation of Fuels (Revue de l'Industrie Minérale, Bulletin, August 1, 1921, pp. 514-519; August 15, pp. 553-554, and September 1, pp. 575-578). The report contains an account of the present state of the pulverised coal question, and has been reviewed and abstracted by P. Gilard, *Heating by Pulverised Coal* (Revue Universelle des Mines, October 1, 1921, vol. 11, pp. 48-56).

Smoke Abatement.—R. E. Swain, *Report on Smoke in Salt Lake Valley* (Chemical and Metallurgical Engineering, March 16, 1921, vol. 24, pp. 463-465). A summary is given of the field conditions surrounding the Murray and Midvale smelters and the resulting effect on human and plant life. The conditions are set forth which will give immunity from damage with reference to the difficulty of maintaining them without hampering progress.

II.—COAL.

United Kingdom.—*Coal, Coke, and By-Products* (Imperial Mineral Resources Bureau: The Mineral Industry of the British Empire and Foreign Countries, London 1921). Part I. of the report deals with the characteristics and composition of coal, coke, and peat in the United Kingdom, low temperature carbonisation, methods of fuel analysis, and the coal industry during the war. Statistics are also given showing the production, imports, and exports of fuel during the period 1913-1919.

Canada.—*The Submarine Coal-Field of Nanaimo, Vancouver Island* (Canadian Mining Journal, March 25, 1921, vol. 42, pp. 228-230). A description of the formation of coal-seams under the bed of the sea, and of the methods of mining and hauling the coal and the ventilation of the workings.

D. B. Dowling, *Underlying Seams of the Souris Coal-Field, South-Eastern Saskatchewan* (Canada Geological Survey, Summary Report, 1920, Part B, pp. 26-29). The character of the seams is dealt with, and typical analyses of the coal are given.

G. A. Young, *Coal-Seams of Gloucester County, New Brunswick* (Canada Geological Survey, Summary Report, 1920, Part E, pp. 1-5).

Italy.—B. Lotti, *The Lignite Mines of Collazzone, Umbria* (Rassegna Mineraria, 1920, vol. 53, pp. 21-22). These mines are on the borders of the ancient Tibur lake in deposits of Pliocene age. The lignite is of good quality, as shown by the analysis: Moisture, 18.70 per cent.; ash, 2.68 per cent.; fixed carbon, 18.41 per cent.; volatile carbonaceous matter, 60.21 per cent.; calorific value (dried), 5555 calories; total sulphur, 2.26 per cent.

Jugoslavia.—D. A. Wray, *The Coal Resources of Jugoslavia* (Iron and Coal Trades Review, June 17, 1921, vol. 102, pp. 816-818). The coal occurrences in Croatia and Slavonia, Bosnia and Herzegovina, Dalmatia and Serbia are described. True coal has nowhere been met with in any quantity in Jugoslavia, and practically the whole of the coals mined are either brown-coals of Mesozoic age, or lignites of Tertiary age. The probable reserves of proved coal amount to

about 1900 million metric tons, of which 90 per cent. are in Bosnia and Herzegovina. The possible reserves included in areas not fully investigated amount to about 2364 million metric tons.

Russia and Siberia.—S. von Bubnoff, *The Coal Resources of Russia* (Glückauf, July 23, 1921, vol. 57, pp. 710-712). According to recent calculations the probable coal resources in European and Asiatic Russia amount to about 424,000 million tons of bituminous and 38,000 million tons of anthracite coal. In the Donetz basin alone there are estimated to be 59,000 million tons, which is all classed as coking coal.

W. Bartels, *Coal Industry of West Siberia* (Glückauf, August 13, 20, 1921, vol. 57, pp. 789-796, 813-817). Coal of good quality is mined in three districts; in the region of Semipalatinsk and Akmo-linsk; in the Kurnezk basin in the Government of Tomsk; and in the division of Minussinsk in the Government of Yenissei. The coal is an excellent coking coal, and the conditions of its development are favourable.

Spitsbergen.—P. Zetzsche, *Coal in Spitsbergen* (Zeitschrift für praktische Geologie, August 1921, vol. 29, pp. 118-124). An account is given of the coal-mining enterprises in operation in Spitsbergen, with particulars of their output and exports. The total quantity exported to Norway in 1920 was 89,000 tons, which, with the exception of bunker coals and some consignments to Sweden, constituted the whole output. An analysis of the coal from Bell Sound shows: Carbon, 83.4 per cent.; hydrogen, 5.8 per cent.; sulphur, 1.1 per cent.; oxygen and nitrogen, 9.7 per cent. The effective heat value is given as 8025 calories. On Bear Island, half-way between the North Cape and Spitsbergen, is found a coal of a much older period, which greatly resembles the South Wales steam coal. About 200 million tons of this coal are estimated to be available.

United States.—M. R. Campbell, *Character of Coal in the Thomas Bed, near Harrison, West Virginia* (United States Geological Survey, Bulletin No. 716-H). Chemical analyses show that this coal is a semi-bituminous or smokeless coal, which is rather high in ash and contains a variable amount of sulphur.

C. M. Bauer and J. B. Reeside, jun., *Coal in the Middle and Eastern Parts of San Juan County, New Mexico* (United States Geological Survey, Bulletin No. 716-G). The quality and character of the coal in this region are described. The coal is chiefly of sub-bituminous rank. The beds, numbering from two to six at most localities, range in thickness from a few inches to 40 feet.

Constituents of Coal.—R. V. Wheeler, *Sulphur in Coal* (Paper read before the Coke-Oven Managers' Association: Iron and Coal Trades Review, June 3, 1921, vol. 102, p. 751). The author discusses the

character and manner of distribution of sulphur compounds in coal.

R. V. Wheeler, *The Oxygen Content of Coals* (Final Report of the Committee on Spontaneous Combustion: Colliery Guardian, August 19, 1921, vol. 122, pp. 516-517). A brief account is given of an investigation on the relative ignition temperatures of different coals. A table shows the results in respect of oxygen contents and relative temperature of self-heating.

E. Erdmann, *Constituents of Bituminous Lignite from which Tar is Derived* (Zeitschrift für angewandte Chemie, 1921, vol. 34, pp. 309-314).

W. A. Bone and L. Silver, *New Method for Determining the Volatile Matter Yielded by Coal up to Various Temperatures* (Transactions of the Chemical Society, 1921, vol. 119, pp. 1145-1152). A weighed quantity of dried finely divided coal is carbonised at a definite temperature in a silica tube, heated in an electric resistance furnace, and provided with an exit tube and a water seal for the exclusion of air. About 5 grammes of coal is weighed into a smaller silica tube, closed at one end, which is pushed, open end first, into a retort tube and kept in position with a silica rod. The retort tube is inclined downwards so as to retain the coal in the smaller tube and prevent tarry matter from draining into it. The tubes are heated to 900°. The complete expulsion of volatile matter is effected in about 40 minutes, and the loss in weight of coal gives the amount of volatile matter yielded.

Composition of Coal.—D. B. Reger, *Analyses of American Coals: Carbon Ratios of Coals in West Virginia Oil-Fields* (Paper read before the American Institute of Mining and Metallurgical Engineers, February 1921, 5 pages). In support of the theory that the ratio of fixed carbon in pure coals is an invariable index of incipient metamorphism in both surface and underground rocks and may be applied in defining the limits of petroleum, an isocarb sketch map is given, together with a number of analyses of coal from various Virginian seams.

C. S. Rice, A. C. Fieldner, and F. D. Osgood, *Analyses of Iowa Coals* (United States Bureau of Mines, Technical Paper, 1921, No. 269). A description is given of the geology of the coal-beds, coal resources, character of the coal, and its coking properties.

Peat.—H. R. Trenkler, *Future Development of the Peat Industry* (Feuerungstechnik, July 15, 1921, pp. 185-186). Deals generally with new methods for the preparation and use of peat and carbonised peat.

III.—COKE.

Coking Coals.—W. Seymour, *Deterioration of Coking Properties of Coal* (Blast-Furnace and Steel Plant, July 1921, vol. 9, pp. 435-

437). The effect of coal storage on the coking properties of coal has been studied, and a number of experiments carried out in order to determine a rapid quantitative test to indicate the percentage of deterioration.

Value of Coke.—Y. A. Dyer, *Characteristics of Foundry Cokes and Slags* (Iron Age, August 18, 1921, vol. 108, pp. 407–409). Some typical analyses of American coke are given and the peculiar characteristics of coke, tests to determine coke characteristics, fluxes for foundry use, and the nature of slags are discussed.

P. Kersten, *The Characteristics of Blast-Furnace Coke* (Revue Universelle des Mines, July 15, 1921, vol. 10, pp. 173–177). The concluding article of a series, giving the summary of the chemical and physical characters of a good blast-furnace coke, which should be :

Physical.—Resistance to crushing 150 kilogrammes per square centimetre (2130 pounds per square inch). 80 per cent. left on screening, moisture 4 per cent. ; grey metallic lustre.

Chemical and Thermal.—Sulphur, 0.95 per cent. ; phosphorus, traces ; ash, 8 per cent. ; volatile matter, 2.55 per cent. ; carbon, 84.5 per cent.

Calorific power, 7000 calories.

Loss through solvent action of CO_2 , 7 per cent.

Coking Practice.—G. E. Foxwell, *The Path of Travel of the Gas in the Coke-Oven* (Journal of Society of Chemical Industry, September 15, 1921, vol. 40, pp. 193–201-T). The author has attempted to determine experimentally the laws governing the flow of gases through coke, crushed coal, and coal in various stages of carbonisation. By a mathematical analysis these laws are found to be similar to those governing the flow through capillary tubes. The resistance of crushed coal to the flow of gas increases when compression is used. The addition of water to the coal increases the resistance, especially with finer coal. During carbonisation the material is in a viscous state at a temperature of about 380–430° C. While in this state, the resistance to the flow of gases is much higher than at any other temperature. The oven is divided into hot and cool zones by a layer of semi-fused material of high resistance, having a temperature of about 400° C. Whether the gases pass up the hot or cool zones is conditioned by the time of charging, the size of coal used, and the moisture content. About one-twentieth of the gas is generated in the low temperature zone.

Temperature Control of By-Product Ovens (Gas World, 1921, vol. 74, No. 1915 (Coking and By-Products Section), pp. 12–13). Heat regulation in oven walls by pyrometric readings is discussed.

Baille-Barrelle, *The Coking of Sarre Coals* (Comptes Rendus, 1921, vol. 172, pp. 1580–1582). By keeping the coke-oven at a temperature below 320° C. until the temperature of the charge is approximately

the same at the centre as at the outside, then raising the temperature at a uniform rate until 750°C . is reached and maintained until coking is complete, a satisfactory coke can be obtained from Sarre coal which will compare with the best Ruhr coke.

H. Koppers, *Progress in the Practice of Coke Manufacture, Influence of the Quality of the Coke on the Blast-Furnace Working, and Suggestions for its Improvement* (Stahl und Eisen, August 25, September 8, 1921, vol. 41, pp. 1173-1181, 1254-1257). It is of extreme importance for the regular working of the blast-furnace that the coke should be easily combustible. Much trouble has lately been experienced through the circumstance that in the desire to coke the mass in the oven thoroughly throughout, parts of it become over-coked, especially when using wet coal. The only means of securing a uniform quality of coke is to ensure that the cakes of coal when charged are always homogeneous and of unvarying quality of coal.

By-Product Coke-Ovens.—*The Wilputte Regenerative By-Product Coke-Oven* (Iron and Coal Trades Review, September 23, 1921, vol. 103, pp. 440-441). In construction this oven differs essentially from all standard types of regenerative ovens in so far as a separate regenerator is provided for each of the vertical heating flues in the oven wall. A battery of sixty of this type of oven is being erected at the works of the Consett Iron Company, Ltd.

The Piron By-Product Coke-Ovens (Iron Age, June 9, 1921, vol. 107, pp. 1531-1533). A description is given of a new type of oven recently introduced in America, and the results obtained with it. The Piron oven is of the general type of horizontal coke-oven. The most prominent characteristic is the continuous heating from the top downward, without inversion of any kind, and the continuous recuperation of heat instead of the usual regeneration. The recuperators are composed of rows of vertical flues, arranged alternately for air and for burned gas in such a manner that the wall between two rows is in contact with the burned gas and with the air from the other side, and transmits the heat continuously from the burned gas to the air.

The Picette Oven (Colliery Guardian, August 19, 1921, vol. 122, pp. 518-519). A brief account is given of this type of coke-oven, which is in operation at several French plants.

Coke-Oven Installations.—*New Coke-Oven and By-Product Plant at the Acklam Works of the North-Eastern Steel Company, Ltd.* (Iron and Coal Trades Review, August 5, 1921, vol. 103, pp. 161-163). The new plant consists of a battery of 60 vertical-flued ovens of the Simon-Carves regenerative type, and is the first instalment of a complete scheme for 120 ovens, together with the complete equipment for the recovery and manufacture of tar, sulphate of ammonia, crude benzol, and naphthalene. The battery produces 2500 tons of coke per week when dealing with a mixture of Durham coals.

Coppée Coke-Ovens at Port Talbot (Colliery Guardian, September 16, 1921, vol. 122, pp. 793-795). The coking plant of Messrs. Baldwins, Ltd., consisting of 120 Coppée ovens, having a weekly capacity of 5800 tons of coke per week, is described and illustrated.

By-Product Coke Plant of the Jones & Laughlin Steel Co. (Chemical and Metallurgical Engineering, May 18, 1921, vol. 24, pp. 891-894). An illustrated description is given of the installation and operation of this plant at Hazelwood, Pennsylvania, which is capable of coking under normal conditions 5000 tons of coal per day. The plant comprises 300 ovens of the standard Koppers cross-regenerative type, in five batteries of sixty ovens each. The inside dimensions of the ovens are: Length, 37 feet between doors; height, 9 feet 10 inches; width, tapering from $18\frac{1}{4}$ to $15\frac{3}{4}$ inches from coke discharge side to pusher side.

Coke-Oven Statistics.—*By-Product Ovens* (Iron Age, August 14, 1921, vol. 108, p. 265). A table is given showing the number of by-product ovens in the United States on May 1, 1921, as 12,245, with an annual capacity of nearly 59,000,000 short tons of coal, yielding about 44,000,000 tons of coke. Particulars are given of the number of ovens owned by each plant.

Low Temperature Carbonisation of Coal.—J. Roberts, *Carbonisation of Coal at Low Temperature* (Paper read before the North of England Institute of Mining and Mechanical Engineers, August 6, 1921: Iron and Coal Trades Review, August 12, 1921, vol. 103, pp. 193-196). The author discusses some of the problems encountered in the production of semi-coke by low temperature carbonisation. The mixing of coke breeze with the coal before charging it into the retort prevents the expansion of the coal and increases the conductivity of the charge, thus reducing the time required for carbonising. Not only is the density, toughness, and hardness of the semi-coke increased, but its texture may be made more uniform by suitable blending.

W. A. Bone, *Low Temperature Carbonisation* (Paper read before the Institution of Mechanical Engineers, June 30, 1921). The advantages and economies to be obtained by low carbonisation of coal, in particular of coal for domestic consumption, are discussed.

The Low Temperature Carbonisation of Coal (Engineer, October 28, 1921, vol. 132, p. 464). A description of the low temperature carbonisation process as carried out in the Davidson retort, made by Low Temperature Carbonisation Co., Ltd., at Barugh near Barnsley. From each ton of slack are obtained 14 cwt. of smokeless fuel, 16 to 18 gallons of tar oil, 6000 cubic feet of gas with a calorific value of 700 B.Th.U. per cubic foot, 14 lbs. of sulphate of ammonia, and from 2 to 3 gallons of motor spirit.

Low Temperature Carbonisation (Colliery Guardian, October 28, 1921, vol. 122, pp. 1207-1208). The carbonisation plant of the Low

Temperature Carbonisation Co., Ltd., Barugh, near Barnsley, and methods of operation are described.

The MacLaurin Carbonisation Process (Iron and Coal Trades Review, June 24, 1921, vol. 102, pp. 848-849). An illustrated description is given of the MacLaurin process and plant, by means of which the fuel is carbonised in an internally heated retort. An account is also given of the trials carried out with this process.

F. S. Sinnatt, *Present Position of Smokeless Fuels* (Paper read before the Royal Sanitary Institute: Iron and Coal Trades Review, August 19, 1921, vol. 103, p. 233). The author briefly outlines the methods of producing the various smokeless fuels, and gives a table showing their approximate analysis.

D. Markle, *Anthra-Coal: A New Domestic and Metallurgical Fuel* (Paper read before the American Institute of Mining and Metallurgical Engineers, September 1921, 11 pages). A mixture of small particles of anthracite coal and a matrix of practically pure carbon formed by the distillation of coal tar, pitch, or other suitable bitumen, is described as harder, tougher, and stronger than coke. It is made from culm with the addition of a binder, well ground and mixed, and then coked, the proportions of the mixture varying from 15 to 25 per cent. of pitch, the lower amounts giving the best results. It is best made in a non-recovery regenerative oven.

H. R. Trenkler, *Carbocite* (Feuerungs-technik, 1921, vol. 9, pp. 93-95). Materials such as lignite, wood, or peat are heated in a retort to a temperature not exceeding 450° C., the water being driven off, thus concentrating the combustible matter. The product carbocite (Karbosit) has about three times the calorific value of the original low-grade material treated.

By-Product Recovery.—A. Grebel, *By-Products of Coal Distillation, Process of Extraction, and Installations at the Boucau Works of the Compagnie de la Marine et d'Homécourt* (Génie Civil, May 28, 1921, vol. 78, pp. 449-454). A description of the plant for benzol recovery and tar distillation.

C. Berthelot, *Development in the Recovery and Treatment of By-Products from Carbonisation of Coal* (Chimie et Industrie, April, May 1921, vol. 5, pp. 384-397, 508-517). Describes the methods for the recovery of sulphate of ammonia and benzol.

F. Sommer, *Increasing the Yield of Ammonia in the Distillation of Coal* (Stahl und Eisen, June 23, 1921, vol. 41, pp. 852-859).

J. Marcusson and M. Picard, *Composition of High and Low Temperature Tars* (Zeitschrift für angewandte Chemie, 1921, vol. 34, pp. 201-204). Analyses of the tars obtained in the high and low temperature distillation of coal have been made, and also of tars obtained in wood distillation. The tars were first separated into saponifiable and unsaponifiable constituents and each group was analysed separately.

G. Cantieny, *Technical Considerations in the Recovery of Primary Tar* (Zeitschrift des Bayerischen Revisions-Vereins, July 15, 31, August 15, 1921, pp. 114-117, 120-123, 132-133).

Seidenschnur, *Influence of the Drying of Brown-Coal on the Yield of Primary Tar, under subsequent Distillation* (Brennstoff-Chemie, August 15, 1921, pp. 241-244). Experience in the distillation of brown-coal briquettes shows that a preliminary drying lowers only very slightly the yield of tar.

H. Tropsch, *Composition of High Temperature and Low Temperature Tars* (Brennstoff-Chemie, August 15, 1921, pp. 251-252). The article describes the results of an investigation of primary coal tar carried out at the Bismarck-hütte.

M. Minot, *Recovery of Hydrocyanic Acid and Carbon Bisulphide from Coke-Oven and Town Gases* (Chimie et Industrie, August 2, 1921, vol. 6, pp. 135-140). The recovery of carbon bisulphide, with illustrations of the plant employed and the mode of operation are described.

IV.—LIQUID FUEL.

Origin of Petroleum.—R. W. Pack, *Origin of Petroleum and Cause of Gas Pressure* (United States Geological Survey, 1920, Professional Paper No. 116, pp. 1-179). The report describes the geology and resources of the Sunset Midway Oil-Field, California. It is shown that the petroleum was generated within the Tertiary deposits, which are at least 18,000 feet thick, ranging from Eocene to Pliocene. The petroleum has originated in the diatomaceous shale formations, chiefly from the alteration of organic matter contained in diatoms and foraminiferas, but probably also in part from the alteration of terrestrial vegetable debris. The pressure in these fields is not proportionate to depth and is usually much in excess of the theoretical hydrostatic pressure. The author puts forth a theory to explain the great gas pressure.

W. Clarkson, *Origin of Natural Oil* (Paper read before the Melbourne Section of the Junior Institution of Engineers: Engineer, May 13, 1921, vol. 131, p. 511). The theory is advanced that natural oil is of vegetable origin, and is derived from plants of aquatic growth.

L. Gentil, *The Origin of Petroleum* (Chimie et Industrie, 1920, vol. 4, pp. 711-721). The author gives an historical and critical review of the various theories regarding the origin and formation of petroleum, with special reference to the work of Mrazec and Murgoci.

J. A. Hardel, *Search for and Mining of Petroleum* (Annales des Mines, 1921, vol. 12, No. 10, pp. 223-321). The first portion of an exhaustive monograph on the search for petroleum and its methods of mining.

Australia.—W. Clarkson, *The Possibility of Oil Discovery on the Mainland of Australia* (Petroleum Times, 1921, vol. 5, pp. 309–311). Extraordinarily rich oil shale exists in almost unlimited quantities in Australia and Tasmania.

Borneo.—J. Kewley, *The Crude Oils of Borneo* (Journal of the Institution of Petroleum Technologists, July 1921, vol. 7, pp. 209–233). A brief outline is given of the chemistry of the crude oils of Borneo, together with an account of their geology. The oils are found in abundance and show a considerable variation in type.

Brazil.—E. P. de Oliveira, *Petroliferous Rocks in Serra da Baliza* (Paper read before the American Institute of Mining and Metallurgical Engineers, September Meeting, 1921, 4 pages). Samples of asphalt and a dark heavy oil have been found in the State of Parana, in the hard vitrified Botacatú sandstone, and afford the most important indications of petroleum hitherto found in Brazil. None of the other rocks show petroleum immediately when freshly broken. Drilling for oil where such asphalts occur should prove promising, particularly at Colonia de Rio Claro, and in São Paulo.

Canada.—J. Ness, *The Search for Oil in the West* (Paper read before the Canadian Institute of Mining and Metallurgy, March 3, 1921: Canadian Mining Journal, April 22, 1921, vol. 42, pp. 313–323). The author describes the features of the oil-bearing regions in Western Canada.

R. C. Campbell-Johnston, *Occurrence of Petroleum in Western Canada* (Mining Journal, September 24, October 1, 8, 15, 22, vols. 134, 135, pp. 710, 729, &c.). A general review of the geological conditions of the region where oil-bearing strata have been found, and of the prospects of developing an extensive production of oil.

A. H. Redfield, *Petroleum in the Canadian North-West* (Engineering and Mining Journal, May 21, 1921, vol. 111, pp. 871–875). The geology, mode of occurrence, and character of the petroleum of the North-West Territories of Canada is described, and a bibliography of literature is appended.

T. O. Bosworth, *The Mackenzie Oil-Field of Northern Canada* (Journal of the Institution of Petroleum Technologists, October 1921, vol. 7, pp. 276–297). The flowing well on the Mackenzie oil-field is on the right bank of the Mackenzie River, within about 90 miles of the Arctic circle. It is the first well drilled in the North-West Territory and the most northerly one in the world. The oil-field is connected with the railroads of Alberta by 1100 miles of navigable waterway. Some notes on the formation of the oil-bearing strata are given.

Mexico.—A. H. Redfield, *The Isthmian Oil-Fields of Mexico* (Engineering and Mining Journal, March 19, 1921, vol. 111, pp. 510–514).

Particulars are given of the structure of the deposits and character of the oil in the Tehuantepec and Tabasco-Chiapas districts.

Scotland.—H. M. Cadell, *Evidence from Recent Bores in the Carboniferous Rocks of Scotland* (Paper read before the British Association, September 1921: Colliery Guardian, September 16, 1921, vol. 122, pp. 796–797). The nature of the oil shale series of the West Lothian is discussed.

United States.—G. L. Martin, *Preliminary Report on Petroleum in Alaska* (United States Geological Survey, 1921, Bulletin No. 719). Indications of petroleum have been found in five districts of Alaska, four of which are on the Pacific seaboard, and one on the Arctic coast. The petroleum of the Pacific coast is a high-grade refining oil with a paraffin base.

A. J. Franks, *Studies in Colorado Shale Oils* (Chemical and Metallurgical Engineering, July 13, 1921, vol. 25, pp. 49–53). Colorado shale oils are very complex, and methods are given for conducting estimations of constituents, having due regard to this complexity. The oils and thin fractions contain much nitrogen, in unstable compounds which give up their nitrogen on cracking.

F. Reeves, *Oil-Fields of Central Montana* (Oil and Gas Journal, 1921, vol. 19, pp. 68–72). An account is given of an area in Central Montana. There are several small producing wells in this field. The oil is a paraffin base containing but little sulphur.

A. R. Schultz, *Oil Possibilities in and around Baxter Basin in the Rock Springs Uplift, Sweetwater County, Wyoming* (United States Geological Survey, Bulletin No. 702). A brief summary is given of the occurrence of oil-shale in the late Tertiary beds around the greater part of the Rock Springs Uplift.

Chemistry of Petroleum.—F. W. Padgett, *The Colloid Chemistry of Petroleum* (Chemical and Metallurgical Engineering, August 3, 1921, vol. 25, pp. 189–192). A description of the two-phase petroleum system found in oil emulsions, with an account of emulsifying agents, and of the effect of the processes employed on lubrication and plant.

I. Lazennec, *Commercial Testing of Petroleum* (Age de Fer, May 31, 1921, vol. 37, pp. 1058–1060). Methods for the commercial evaluation of the flash point, viscosity, density, and other physical and chemical characters of petroleum are given.

Distillation of Petroleum.—D. E. Day, *Distillation of Oil Shale* (Mining and Scientific Press, August 20, 1921, vol. 123, pp. 257–262). The factors affecting the efficient and economical recovery and distillation is discussed. The Day-Heller retort is described.

Uses of Oil.—N. A. Anfilogoff, *Liquid Fuel for Steam-Raising* (Journal of the Society of Chemical Industry, June 15, 1921, vol. 40, pp. 205–209–R). In practically all industries fuel oil can advantageously replace coal as a source of heat and power, and for steam raising liquid fuel is beyond compare the more efficient fuel of the two. Its efficient combustion depends on combustion-area, and two essentials are necessary: the provision of means to convert the oil into a heavy vapour, and the provision of sufficient air to support combustion. The general arrangement of a modern installation for firing a tubular boiler is illustrated and described.

V.—NATURAL GAS.

Extraction of Helium from Natural Gas.—C. S. Rogers, *Helium-Bearing Natural Gas* (United States Geological Survey, 1921, Professional Paper, No. 121). The report is based on the results of an investigation of the helium resources of the United States, and describes the distribution of helium-bearing natural gas, and briefly refers to the technologic problems involved in the extraction and purification of helium.

VI.—ARTIFICIAL GAS.

Relative Heat Value of Different Gases.—W. A. Bone and W. A. Haward, *Gaseous Combustion at High Pressures. Part II. The Explosion of Hydrogen-Air and Carbon Monoxide-Air Mixtures* (Proceedings of the Royal Society, October 4, 1921, Series A, vol. 100, pp. 67–84). It has been assumed, as recently as 1919, by the Fuel Research Board, that the relative values of different combustible gases are strictly proportional to their heats of combustion, irrespective of their chemical characters or modes of combustion. This view is shown to be wrong: the fundamental properties of the explosive mixtures formed by different combustible gases with air, arising from their own peculiar chemical characters and compositions, profoundly affect their economic uses. The importance of the chemical composition of a gas or mixture is a factor which cannot be disregarded.

Gasification of Coal Dust.—K. M. Balley, *A New Process for the Gasification of Coal Dust* (Chemiker Zeitung, August 18, 1921, pp. 789–790). The coal dust is sprayed through a current of superheated steam and is then brought into contact with highly heated bodies, such as glowing coke or heated checker work, where the gases evolved are converted to water-gas.

By-Products from Producer-Gas.—Gwosdz, *The Manufacture of Producer-Gas with Special Reference to Recovery of By-Products* (Braunkohle, June, 30, 1921, pp. 193–196). Some observations are made on the regulation of the air and steam supply to producers.

Wood Gas-Producers.—Gwosdz, *The Gasification of Wood in Gas-Producers* (Brennstoff-Chemie, 1921, vol. 2, pp. 21–23). The author reviews the various attempts to utilise wood in gas-producers and describes the Deutz and Pintsch types of producers designed for that purpose.

Substitute for Natural Gas.—F. J. Denk, *Elliott Gas: A Substitute for Natural Gas* (Forging and Heat Treating, April 1921, vol. 7, pp. 208–212). A description is given of the method of producing Elliott gas, which is a combination of coal and water gas made from bituminous coal. An average of 22 cubic feet of gas can be produced from one pound of good bituminous coal with a heating value of 500 B.Th.U. per cubic feet. To increase the heating value all the by-products are turned into fixed gas, at the same time reducing to a certain extent the quantity of pure water-gas made.

Coke-Oven Gas.—*The Use of Coke-Oven Gas* (Board of Trade Journal, July 7, 1921, vol. 107, pp. 3–4). The Board of Trade have recently endeavoured to obtain information regarding the quantity of coke-oven gas produced in the United Kingdom and the proportions used for various purposes, and, whilst the returns are not complete, it is estimated that a total quantity of 37,250 million cubic feet per annum is utilised at the works for purposes other than heating the coke-ovens, and a total of 7,250 million cubic feet per annum, including upwards of 805 million cubic feet run to waste, is at present available for disposal, being in some cases already utilised for public consumption.

Gas-Fired Boilers.—W. Gregson, *Recent Developments in Gas-Firing Steam Boilers and the Utilisation of Waste Heat on the Bonecourt System* (Proceedings of the South Wales Institute of Engineers, 1921, vol. 36, pp. 279–314, 489–508).

Gas-Engines.—H. A. H. Dombrain, *Notes on the Schneider Gas-Engine* (Electrician, November 18, 1921, vol. 87, pp. 643–646). An illustrated description is given of the Schneider gas-engine. It is made in four types: single cylinder, twin single cylinder, tandem, and twin tandem, the last enabling powers as high as 6000 horsepower to be attained normally. They are all horizontal and four-stroke.

VII.—COAL WASHING AND HANDLING.

Preparation of Coal.—D. C. Ashmead, *Advances in the Preparation of Anthracite* (Paper read before the American Institute of Mining and Metallurgical Engineers, September 1921, 85 pages). Deals in detail with the various operations necessary in the preparation of anthracite coal for market and illustrates the plant and appliances used in crushing, sizing, and grading.

Briquetting of Brown-Coal.—Berner, *Loss of Combustible Matter in the Briquetting of Lignite* (Chemiker Zeitung, 1921, vol. 45, pp. 333–335). Assuming the raw material to contain 45 per cent. of moisture, and the finished briquettes 15 per cent., it appears that it requires 1·867 kilogrammes of lignite, including that used for drying, to produce 1 kilogramme of briquettes. If the raw fuel contains 60 per cent. of moisture, the total weight of lignite used and consumed becomes 3·081 kilogrammes for making 1 kilogramme of briquettes.

Landsberg, *Briquetting of Brown-Coal* (Zeitschrift des Vereines Deutscher Ingenieure, April 16, 1921, vol. 65, pp. 415–417).

Coal Cleaning.—R. Nelson, *Recent Developments in Coal-Cleaning Processes* (Paper read before the Engineering Conference of the Institution of Civil Engineers: Iron and Coal Trades Review, July 1, 1921, vol. 103, p. 10). The author refers to the froth flotation method for the cleaning of fines.

F. B. Jones, *The Froth Flotation of Coal* (Paper read before the South Wales Institute of Engineers: Iron and Coal Trades Review, September 30, 1921, vol. 103, pp. 472–473). The very high efficiency of the froth flotation method makes it eminently suitable for the cleaning of raw coal, owing to the completeness of the resultant separation of the coal from the impurities.

S. St. J. Perrott and S. P. Kinney, *The Use of Oil in Cleaning Coal* (Chemical and Metallurgical Engineering, August 3, 1921, vol. 25, pp. 182–188). An account of the Trent process which consists in agitating together powdered coal, water, and oil, yielding a partly de-ashed plastic fluid called an amalgam which can be freed from water and either shovelled direct, forced through pipes, or even stored under water. The United States Bureau of Mines has investigated the process and considers that real benefits result from its application. Combustible recovery averages over 95 per cent. and oil losses are practically negligible. High ash reduction is obtained with all coals, and sulphur reduction in the case of anthracites.

O. P. Hood, *Trent Process for Cleaning Powdered Coal* (Iron Age, August 11, 1921, vol. 108, p. 323).

Coal Handling.—*Coal Handling Plant for the Han-Yeh-Ping Iron and Coal Company, China* (Iron and Coal Trades Review, June 10, 1921, vol. 102, pp. 779–780). The plant is designed for discharging boats at the staith on the Yangtse River, and consists of a specially designed dredger working in conjunction with a system of conveyers.

PRODUCTION OF IRON.

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I.—MANUFACTURE OF PIG IRON.

Blast-Furnace Plant and Equipment.—*Blast-Furnace Plant of the St. Louis Coke and Chemical Co.* (Iron and Coal Trades Review, August 26, 1921, vol. 103, pp. 257–258). This plant is at Granite City, Illinois, and was put into operation in the early part of this year. The furnace is 86 feet high, and has a bosh $20\frac{1}{2}$ feet in diameter. Its capacity is 19,600 cubic feet, and it is rated at a daily production of 500 tons. The gas washer is of the Brassert type.

R. Peters, jun., *Historical Iron Plant* (Iron Trade Review, September 29, 1921, vol. 69, pp. 803–806). An illustrated description is given of the new 90 feet blast-furnace of the Empire Steel and Iron Co., Catasauqua, Pennsylvania.

R. Peters, jun., *New Blast-Furnace of the Crane Iron Works* (Iron Age, September 29, 1921, vol. 108, pp. 814–817). The furnace, which is at Catasauqua, Pa., is 90 feet in height, hearth and bosh diameter of 15 feet and 20 feet 5 inches respectively, and a 78° bosh.

New 600-ton Blast-Furnace (Iron Trade Review, September 15, 1921, vol. 69, pp. 688–693; Iron Age, September 15, 1921, vol. 108, pp. 673–679). The new 600-ton blast-furnace and equipment of the Trumbull Cliffs Furnace Co. is described and illustrated.

Special Features of Blast-Furnace Plant (Iron Age, September 22, 1921, vol. 108, pp. 730–731). The methods of firing the boilers, regulation of the blast, and of handling the water at the above blast-furnace plant is described.

L. Delville, *The Standard Type of Works in Europe and America* (Revue de l'Ingénieur et Index Technique, vol. 25, pp. 199–209, and vol. 26, pp. 261–265; Revue Universelle des Mines, July 15, 1921, vol. 10, pp. 218–221). Institutes a comparison between American and Continental practice, taking the Lorraine and Luxemburg works as standard types.

H. R. Stuyvesant, *Stack Changes Effect Economy* (Iron Trade

Review, May 12, 1921, vol. 68, pp. 1312-1313). The improvements in the design, lines, and distribution of the blast-furnaces of the Alabama Co., Gadsden, Alabama, are described. The improvements, together with the installation of a pig-casting machine, have resulted in a great reduction in labour.

New Type of Downcomer (Iron Age, June 9, 1921, vol. 107, p. 1539). A brief description is given of a new type of McKee downcomer. The gas and particles of stock travel initially in the direction of the inclined outlet from the furnace, but the gas turns at a sharp angle from this direction in order to enter the vertical branch. Moreover this gas must pass a baffle. It has been demonstrated that the fine material, except the very small particles, strikes the end of the inclined pipe and falls back into the furnace, the diverted flow of the gas not having sufficient carrying power to cause a change upward from its original direction of the fine stock in suspension.

New Use of Recording Instruments (Blast-Furnace and Steel Plant, August 1921, vol. 9, pp. 472-474). The installation of Bristol recording instruments at the blast-furnace plant of the Weirton Steel Co., West Virginia, is described.

H. Barral, *Inclined Furnace Hoist on the Husson Inclined System* (Revue de Métallurgie, Mémoires, February 1921, vol. 18, pp. 92-95). An illustrated description of a modification of the Staehler double bell top and charger, known as the Husson system. This modification is one which, by its nature, can easily be introduced at comparatively small cost, in any furnace charging system which depends on inclined hoists.

Blast-Furnace Charging Installations (Stahl und Eisen, July 14, 21, August 4, vol. 41, pp. 945-954, 994-999, 1064-1071). Illustrated descriptions are given of the blast-furnace charging installations at the Rheinische Stahlwerke, at the works of the Bochumer Verein, and at the Gelsenkirchen works. These show the latest practice in the design of charging plant, as carried out to meet the conditions of German blast-furnace practice. A long discussion on the various types of charging appliances is also published. *Ibid.*, August 11, 1921, pp. 1097-1103.

Pig Casting Machine (Iron Age, May 26, 1921, vol. 107, pp. 1384-1385). The pig casting equipment erected at the Hamilton Works of the Steel Co. of Canada is briefly described.

C. F. Poppleton, *Mechanical Handling of Steel Mill Material* (Blast-Furnace and Steel Plant, May 1921, vol. 9, pp. 291-298). The appliances for handling raw materials and hot metal, including modern blast-furnace charging equipment, metal transfer cars and ladles, are described.

G. L. Collord, *Crane Operating Costs at Blast-Furnaces* (Iron Age, October 13, 1921, vol. 108, pp. 935-936). Particulars are given of the cost of operation of locomotive and ore bridge cranes at an American blast-furnace plant. The furnaces are equipped with Brownhoist equipment.

Blast-Furnace Stoves.—W. E. Groume-Grjmailo, *Design and Proportions of Hot-Blast Stoves* (Iron Age, June 9, 16, 23, 1921, vol. 107, pp. 1527–1530, 1613–1616, 1677–1680). The laws governing the circulation of gases are considered, and a review is given of the historical development of hot-blast stoves.

D. W. Wilson, *Heat Balance of a Blast-Furnace Stove* (Chemical and Metallurgical Engineering, August 3, 1921, vol. 25, pp. 200–202). Investigations carried out on a vertical cylindrical stove lined with firebrick, 22 feet in diameter and 110 feet high, of the two-pass type, the gas for which is cooled and cleaned. An efficiency figure of 62 per cent. was obtained. The radiation loss was 10·1 per cent., which is believed to be reliable up to 2 per cent. The unaccounted loss is returned at 6·7 per cent. Future lines of investigation are indicated.

Blast-Furnace Practice.—A. Anderson, *Blast-Furnaces and the Making of Pig Iron* (Transactions of the American Society for Steel Treating, March 1921, vol. 1, pp. 312–320). The author gives a brief outline of the manufacture of pig iron.

J. F. Shadgen, *Secure Place of the Blast-Furnace* (Iron Age, August 25, 1921, vol. 108, pp. 465–467). The blast-furnace process is outlined, and the heat balance of the blast-furnace is given.

V. Falcke, *The Reactions between Iron Oxide and Carbon and between Carbon Monoxide and Iron* (Zeitschrift für Elektrochemie, June 1, 1921, vol. 27, pp. 268–278). The article mainly reviews the work of previous investigators on the equilibrium of the reactions between iron oxide and carbon, and between carbon monoxide and iron.

C. R. Peebles and R. H. Sweetser, *Rating Blast-Furnace Capacities* (Paper read before the American Institute of Mining and Metallurgical Engineers: Iron Trade Review, August 18, 1921, vol. 69, pp. 430–432). The fuel capacities of blast-furnaces are discussed. The Southern Ohio Pig Iron and Coke Association in August 1920 adopted a rule for finding the capacity of a blast-furnace—one that would apply to all sizes of furnaces making all grades of pig iron. The rule states that from figures prepared on a number of different-sized furnaces, it has been found that with good practice 60 lbs. of coke can be burned each twenty-four hours per cubic foot working volume. The working volume is taken as the volume from centre line tuyeres to 2 feet below the bell when closed.

J. L. Avis, jun., *Making Pig Iron and Steel from Pacific Coast Black Sands* (Iron Trade Review, September 29, 1921, vol. 69, pp. 810–812). Investigations show that this sand, which is found in large quantities on the Pacific Coast, contains more than 50 per cent. of iron. The process of smelting the sand, which was developed by W. Tyrrell, consists in smelting iron sand briquettes in a blast-furnace, the charge being approximately 47 per cent. fuel, 47 per cent. briquettes, and 5 per cent. flux. The average analysis of the briquettes is as

follows: Iron, 54.0; titanium oxide, 11.0; silica, 7.0; and phosphorus, 0.018 per cent.

The pig iron contains 2.75 per cent. graphitic carbon, 0.98 combined carbon, 0.60 phosphorus, 0.08 sulphur, and 1.25 silicon.

Steel castings have been produced from a mixture of about 39 per cent. open-hearth scrap, 44 per cent. foundry scrap, and 16 per cent. black sand pig iron in an electric furnace.

Blast-Furnace Gases.—A. Hutchinson and F. Bainbridge, *Blast-Furnaces Gases* (Paper read before the Institution of Mechanical Engineers: Iron and Coal Trades Review, July 1, 1921, vol. 103, p. 12). The developments in the cleaning and utilisation of blast-furnace gas are reviewed. The cardinal feature of the new development is to concentrate coke-ovens, blast-furnaces, steelworks, and rolling-mills in one plant, coupled with the utmost utilisation of the surplus gases for power and heating purposes.

N. H. Gellert, *Some Points in the Design of Blast-Furnace Gas Cleaners* (Chemical and Metallurgical Engineering, August 17, 1921, vol. 25, pp. 287–288). Contains methods and formulæ for determining the velocity and moisture content of hot gases flowing through large pipes, and calculations required for a heat interchanger designed to cool the gases from a blast-furnace working on ferro-manganese and issuing at 1200° F. to 400° F. without increasing the absolute humidity.

N. H. Gellert, *Extracting Flue Dust Electrically* (Paper read before the Association of Iron and Steel Electrical Engineers: Iron Trade Review, July 14, 1921, vol. 69, pp. 102–105; Iron Age, August 11, 1921, vol. 108, pp. 329–334). The principles involved in precipitating dust by the Cottrell process, and the method of operating an electrolytic cleaning plant are described.

H. Thein, *Gas Cleaning by Electricity* (Zeitschrift für technische Physik, 1921, Nos. 7 and 8, pp. 177–178, 201–209). The principles underlying the application of electricity to gas cleaning are explained. The best form of electrode is that with parallel cylindrical surfaces. Direct current should be used. The precipitation of dust is effected by the incoming current, the air current set up, and the direct effect of the electric field on the suspended particles. The electrical method is thought to be suited for cleaning to a high degree (fine cleaning). The cost of cleaning is about one-half that of the wet or dry system.

J. Seigle, *Theoretical Considerations as to the Composition of Combustible Gases and the Gasification of Carbon* (Revue de Métallurgie; Mémoires, February 1921, vol. 18, pp. 81–91). Considers the theory of the gasification, (1) of carbon by itself, (2) by dry air, (3) by air containing more or less oxygen, carbonic acid, and water vapour; and the thermal and chemical balance-sheets relating to the gaseous products of the blast-furnace process, (a) in ordinary practice, and (b) in electric blast-furnaces.

O. Johannsen, *Blast-Furnace Gas Poisoning* (Stahl und Eisen,

August 18, 1921, vol. 41, pp. 1141-1143). In several instances mental derangement has occurred as the result of blast-furnace gas poisoning, and it has been suggested that risk of poisoning is increased by the greater degree of cleaning or the effects are connected in some way with the method of cleaning. These suggestions are shown to be unfounded.

Electric Smelting of Iron.—H. A. Fries, *Electric Reduction of Iron Ores* (Chemical and Metallurgical Engineering, August 3, 1921, vol. 25, pp. 193-194). Descriptions are given of the smelting of iron ores both in electric pit furnaces and in shaft furnaces. Pit furnaces are employed at Porjus, in Sweden, where a 600 k.v.a. furnace produces 6 tons of pig iron per twenty-four hours. Another example given is of the reduction of pyrite cinders which are first roasted in a rotary drier. Shaft furnace practice is then discussed in reference to the use of black sands containing titania. The conclusions are reached that for lumpy ore and sintered concentrates the shaft furnace is best, while for crude concentrates or a variable ore supply pit furnaces should be used.

R. Durrer, *The Metallurgy of the Electric Shaft Furnace* (Stahl und Eisen, June 2, 1921, vol. 41, pp. 753-757).

Iron Industries of Various Countries.—J. Horton, *British Iron and Steel Centres* (Iron Trade Review, May 5, 19, June 9, 23, July 21, August 18, September 1, 1921; vol. 68, pp. 1246-1250, 1388-1390, 1590-1592, 1597-1598, 1721-1722; vol. 69, pp. 163-166, 433-435, 556-558). A description of the ore and pig iron producing areas, and chief steel-making plants in the United Kingdom.

E. Bury, *Proposed South African Iron Works* (Iron and Coal Trades Review, September 23, 1921, vol. 103, p. 435). As adviser to the South African Iron and Steel Corporation, the author has had to investigate the quality and extent of the reserves acquired by them. He is able to confirm that these mineral reserves are adequate to ensure the requirements of an iron and steel works of large capacity for at least one hundred years. In conclusion, he states that a good case is established for the foundation of an iron and steel industry in South Africa.

Herdsmen and Poole, *Developments of Iron and Steel in South Africa and Australia* (Journal of the West of Scotland Iron and Steel Institute, Session 1920-1921, vol. 28, pp. 80-91).

Partition of Upper Silesia (Mining Journal, November 5, 1921, vol. 135, p. 822). A list is given of the coal-mines, iron-mines, iron and steel works, and other metallurgical undertakings which have passed into the possession of Poland as the result of the division of the province of Upper Silesia.

II.—BLAST-FURNACE SLAGS.

Classification of Slags.—W. G. Imhoff, *Colour Classification of Blast-Furnace Slags* (Blast-Furnace and Steel Plant, July 1921, vol. 9, pp. 433–434). The characteristics and composition of blast-furnace slags and their classification are discussed. A bibliography is given of the literature on the subject.

Recovery of Sulphur from Slag.—L. H. Diehl, *The Recovery of Sulphur from Blast-Furnace Slag* (Stahl und Eisen, June 23, 1921, vol. 41, pp. 845–852). Diehl's process for the utilisation of the sulphur in slag consists in the recovery of sulphurous acid by oxidation of the sulphate of lime in the slag by means of air or by means of sulphates, such as gypsum with the addition of air. The carrying out of the process on a large scale is thought likely to become a very profitable enterprise.

Strength of Slag.—H. Burchartz, *Strength of Blast-Furnace Slag* (Stahl und Eisen, April 7, 1921, vol. 41, pp. 472–475). Results of mechanical tests on blast-furnace slag are given. The compression strength of cubes of 4 centimetres height, representing ten different slags, varied from $\frac{3}{4}$ ton to $2\frac{1}{2}$ tons per square centimetre. Friction tests in a revolving drum were also made.

Preparation of Slag.—H. v. Schwarze and W. Schäfer, *Preparation of Slag for Use on Permanent Ways* (Stahl und Eisen, July 7, 1921, vol. 41, pp. 919–923). A description of the slag-handling and crushing plant at the Georgs-Marien-Hütte, Osnabrück, and at Krupp's Rheinhausen Works. The slag is broken and graded for making the permanent way on railways and for packing the sleepers.

Methods of Preparing Blast-Furnace Slag (Iron Age, August 25, 1921, vol. 108, pp. 461–463). The practice at the plants of the Carnegie Steel Co. for the disposal of blast-furnace slag is described. There are four methods for treating the slag. The air-cooled slag is deposited on dumps, and is the source of the principal commercial slag. Fork slag is run into long narrow trenches and allowed to cool, afterwards being broken with sledges, and is suitable for mass concrete and road work. Pancake slag is cast upon a machine into large flat slabs; the cooling is accelerated by sprinkling with water. Much of this form of slag is used as a concrete aggregate in fireproof construction. Honey-comb slag is granulated by being run directly from the furnace into tanks, to a depth of 6 inches, and sprayed with water, cleansed, and dried; then another 6-inch layer of slag is poured, and water sprayed until the tank is full. Granulated slag is cooled by water immediately on its passage from the blast-furnace, and is used in the manufacture of Portland cement.

Uses of Slag.—*Slag Cement Manufacture in Electric Furnaces* (Engineering, July 15, vol. 112, pp. 103–104). A brief description is given of the method of manufacturing cement from blast-furnace and other slags in a 3-ton electric arc furnace at the works of the Stora Kopparberg Company at Domnarfvet.

R. Grün, *Blast-Furnace Slag and its Use for Building* (Zeitschrift für angewandte Chemie, March 18, 1921, vol. 34, pp. 101–102). Notwithstanding the wide variation in the composition of blast-furnace slag, practically any slag suitably treated by the addition of lime and alumina can be utilised for making slag cement, or iron Portland cement. The mixture can be heated in an electric furnace.

C. R. Platzmann, *Blast-Furnace Slag in the Building Industry* (Ton-industrie Zeitung, March 24, 1921, pp. 294–296).

III.—DIRECT PROCESSES.

L. Wickenden, *Smelting Ore by Direct Process* (Iron Trade Review, August 11, 1921, vol. 69, pp. 363–368). The Bourcoud process is described. The ore is subjected to a preliminary roasting before being fed into a rotating reducing furnace at about 750° to 850° C. The reduced ore, together with its original gangue and flux, is continuously discharged by the reducing furnace into a machine which automatically compresses it and feeds it, at about 900° to 1000° C., into a primary tilting electric melting furnace through its axis of rotation. This furnace works at a sufficient temperature to separate the slag formed from the metallic iron. The metal is tapped from this furnace into a ladle for conveyance to the electric refiners. A residual charge is left in the preliminary melter to act as a heat mass for the constantly charged hot sponge. The thermal calculations of the process are given.

N. Statham, *The Canadian Steel Industry and the Direct Process* (Iron and Steel of Canada, May 1921, vol. 4, pp. 91–98). The Bourcoud open cycle direct process is described, together with particulars of costs per ton of steel by this process, as compared with open-hearth practice.

E. Houbaer, *A New Direct Process for the Manufacture of Iron and Steel* (Revue Universelle des Mines, October 1, 1921, vol. 11, pp. 45–47). A short description of the Bourcoud process is given.

H. Lang, *Direct Process for Steel Making* (Iron Age, May 12, 1921, vol. 107, pp. 1237–1238). Pulverised iron ore is mixed with carbonaceous fuel, either liquid or solid, and together with the necessary fluxes is placed in a retort of spherical or cylindrical shape. The retort is charged into the cool end of a long reverberatory furnace, with a sloping hearth to facilitate the travel of the retort. The furnace contains a melting compartment and a reducing furnace, separated

by a door. When the charge is reduced, the door is opened and the retort allowed to roll into the melting compartment where it, with its contents, is melted down, producing liquid steel.

Making Steel Direct from Ore (Iron Trade Review, May 19, 1921, vol. 68, pp. 1375-1376). The Basset and Jones processes are compared, and reference is made to the plant which is being erected for the Direct Steel Process Co., Santa Cruz, California, for the utilisation of magnetic iron sands. The equipment will comprise four reduction furnaces in which the ore is reduced to iron sponge, a melting furnace, and an electric refining furnace. Pulverised ore mixed with fuel and the necessary fluxes is contained in closed receptacles, or retorts. These retorts travel through the reducing furnace by gravitation, where the ore is reduced to sponge, which is melted, along with the retort, in the melting furnace.

W. F. Sutherland, *Steel Direct from Ore by Moffat Process* (Iron Age, June 2, 1921, vol. 107, pp. 1450-1452). Recent improvements in this process are described. Ore is reduced and transferred to an electric furnace in the spongy state.

Levoz Process for the Direct Reduction of Iron Ore in the Manufacture of Iron and Steel (Rassegna Mineraria, 1921, vol. 54, pp. 29-30). The process is carried out in three stages in a specially designed electric furnace. The oxides of iron, manganese, and silicon in the charge are reduced in the first stage. In the second stage some of the Al_2O_3 introduced with the charge is reduced, giving an iron free from carbon and containing silicon, calcium, and aluminium. In the third stage the impurities are oxidised to a fusible slag, the heat of the reaction carrying the metal to a very high temperature. Cryolite is added to facilitate the reactions and the separation of the slag.

T. T. Read, *Primitive Iron Smelting in China* (Iron Age, August 25, 1921, vol. 108, pp. 451-454). The native method of smelting iron in the Ping-ting-chou region of Shansi Province, China, is described and illustrated. The ore is mixed with half its weight of coal and packed into cylindrical formed clay crucibles 5 inches in diameter and about 4 feet long. From 250 to 275 of these crucibles are set upright inside an enclosure 12 by 6 by 4 feet. Spaces for the entrance of air are provided by the interstices between the loosely laid butts of old crucibles which form the floor of the enclosure. Over these is spread a layer of coal; the crucibles are set in place, with coal between them until the enclosure is full. The furnace is lighted at the bottom and allowed to burn by natural draught for three days. The front is then taken down, and the crucibles removed. Near the bottom of the crucible the heat has been sufficiently intense for the particles of iron to fuse together into an irregular bloom, but near the top the iron is in separate particles. The coal inside the crucible is not all consumed in the process, but is partly converted into coke. The bloom is heated in a wood fire and hammered free of slag, and finally worked up into the finished product.

FOUNDRY PRACTICE.

Cupola Practice and Design.—Y. A. Dyer, *Chemical Reactions in Foundry Cupolas* (Iron Age, August 4, 1921, vol. 108, pp. 259–262). The author discusses combustion, carbon ratio, gases, melting efficiency, and heat balance.

Y. A. Dyer, *Design of Cupola and Accessory Areas* (Iron Age, May 19, June 23, 1921, vol. 107, pp. 1312–1314, 1347–1348, 1675, 1727–1729). The factors determining the design of cupolas are discussed.

J. Horner, *The Design and Equipment of an Iron Foundry* (Foundry Trade Journal, June 23, 30, 1921, vol. 9, pp. 555–558, 573–575).

Foundry Irons.—Y. A. Dyer, *Foundry Irons for Particular Uses* (Iron Age, September 8, 1921, vol. 108, pp. 585–588). The characteristics of grey, mottled, and white irons are discussed, and a number of analyses are given of irons suitable for certain castings.

Y. A. Dyer, *Charges for Foundry Irons* (Iron Age, October 13, 1921, vol. 108, pp. 931–933). The calculation of cupola charges is discussed, and a list is given of suggested analyses for different castings.

E. Lecron, *The Use of Synthetic Pig Iron in the Steel Foundry* (Fonderie Moderne, July 1921, pp. 177–181). Very successful results have been obtained by the refining of synthetic pig iron in the small converter and in the basic open-hearth furnace, the product being remarkable for its low sulphur content.

A. Harley, *Composition of Iron for Piston Rings* (Paper read before the Institution of British Foundrymen, June 1920).

General Foundry Practice.—J. H. Hopp, *Mechanical Control in Foundry Problems* (Paper read before the Southern Metal Trades Association: Iron Age, August 25, 1921, vol. 108, pp. 456–458). The control of correct casting and moulding operations is discussed.

E. Ronceray, *Pouring Castings without Runners* (Foundry Trade Journal, July 7, 1921, vol. 24, pp. 3–7). The method of pouring castings by means of a thin jet or gate is discussed. This method is said frequently to permit of the complete suppression of feeding heads.

H. Measures, *Some Experiments of Pouring Castings without Runners* (Foundry Trade Journal, July 14, 1921, vol. 24, pp. 35–36).

E. Ronceray, *Pouring Castings without Feeding Heads* (Foundry Trade Journal, August 11, 1921, vol. 24, pp. 108–109).

Melting Cast Iron Scrap (Iron Age, June 23, 1921, vol. 107, pp. 1686–1921—ii. 2 B

1687). The application of the non-ferrous electric melting furnace to the melting of cast iron has been investigated by the Electric Furnace Co. Alliance, Ohio, and the results are given. The furnace used was one of the standard 105 kilowatt Baily furnaces.

Steel Foundry Practice.—G. K. Elliott, *The Basic Hearth Electric Furnace and Some Problems of Cast Iron* (Paper read before the Institution of British Foundrymen, September 1921 : Foundry Trade Journal, September 22, 1921, vol. 24, pp. 236–240). The use of the electric furnace for refining cupola metal is discussed. The most interesting feature of refining in the basic electric furnace is desulphurisation. The greatest reduction of sulphur in grey iron made by the author was from 0·171 in the cupola melt to 0·013 per cent. in the same iron refined in the electric furnace, with a single slag in eighty minutes.

F. W. Brooke, *Acid versus Basic Electric Furnace for the Foundry* (Chemical and Metallurgical Engineering, April 27, 1921, vol. 24, p. 794). For steel foundry work acid furnaces are suitable, when the sulphur and phosphorus are below the amount which the finished castings should contain, when a wide range of carbon and silicon may be allowed, and when very small castings only are required. The basic furnace should be installed when the conditions are the opposite of the foregoing and when alloy steels are the object of manufacture.

Cost of Melting Steel (Iron Trade Review, July 21, 1921, vol. 69, pp. 167–170). Particulars are given of the costs of operating an electric furnace and an open-hearth furnace for the production of steel castings.

Nickel Cast Iron.—D. N. Witman, *Making a 5 per Cent. Nickel Cast Iron Alloy in an Electric Furnace* (Paper read before the American Institute of Mining and Metallurgical Engineers, September 1921, 4 pp.). An account of the manufacture of electrical resistance grids with 2·4 to 2·6 per cent. of silicon ; low sulphur, phosphorus, and manganese ; 3·6 to 4·0 per cent. of carbon, 4 to 5 per cent. of nickel, and 0·50 to 0·70 per cent. of copper in a small three-phase electric furnace.

Centrifugal Castings.—E. C. Kreutzberg, *Mould Serves as Electric Furnace* (Iron Trade Review, July 7, 1921, vol. 69, pp. 33–35). A description is given of the Cammen centrifugal casting process, in which the metal is melted electrically in a revolving mould.

Tests of Centrifugally Cast Steel (United States Bureau of Standards, 1921, Technical Paper No. 192). The physical and chemical properties of six centrifugal castings made by the Millspaugh process were examined. The results show that highly satisfactory castings which are physically sound and free from serious segregation can be produced by the centrifugal process. The properties of these castings

can be improved greatly by subsequent heat treatment, to compare favourably with metal that has been forged.

Cast Iron from Pyrites Cinders.—M. Guédras, *The Manufacture of Cast Iron from Pyrites Cinders in the Electric Furnace* (Technique Moderne, 1920, vol. 12, pp. 301–304). Pyrites cinders from sulphuric acid manufacture contain 94 per cent. Fe_2O_3 , 3 per cent. SiO_2 , and 2.75 to 3.5 per cent. S. Economical desulphurisation had not been effected before the introduction of the Guédras-Duina patent. This process combines complete dehydration, desulphurisation, agglomeration in a horizontal rotating furnace at 1000° to 1200° C., and reduction with coke, charcoal, and anthracite in a Siemens electric furnace. The desulphurisation is due partly to the action of lime or mineral slags added. The probable reaction is $\text{FeS} + \text{CaCl}_2 + \text{CO} = \text{Fe} + \text{CaS} + \text{COCl}_2$. The COCl_2 then reacts with FeS, freeing the sulphur and thus keeping slag from saturation with CaS. The product is high grade iron (0.001 to 0.3 per cent. of sulphur).

Foundry Sands.—W. H. Roesner, *The Manufacture of Steel Castings in Green Sand* (Foundry: Foundry Trade Journal, August 25, 1921, vol. 24, pp. 146–147). The sand should have a high silica content and be open and free venting. The use of this sand in moulding is described.

G. Pouplin, *Moulding Sand for Iron, Steel, and Brass Foundries* (Fonderie Moderne, July 1921, pp. 197–199). General information on the qualities of moulding sand, with analyses of French moulding sands.

Moulding and Core-Making.—A. Wardle, *Jolt Ram Machines* (Paper read before the Institution of British Foundrymen, April 2, 1921: Foundry Trade Journal, June 2, 1921, vol. 23, pp. 499–501). The construction and operation of various types of jar-ramming moulding machines are described.

U. Lohse, *Modern Moulding Machines of Jarring Type* (Stahl und Eisen, September 1, 29, 1921, vol. 41, pp. 1209–1214, 1367–1375). The guiding principles in the design of jarring moulding machines are discussed, and various recent types of such machines are illustrated and described.

E. Longden, *Moulding Heavy Fly Wheels* (Foundry Trade Journal, August 18, 1921, vol. 24, pp. 131–132). In the method of moulding described, only one-half pattern is used to make two half-moulds, which on assembling make a full wheel.

Novel Mechanical Moulding of Car Wheels (Iron Age, September 15, 1921, vol. 108, pp. 662–664). At the plant of the Brown Car Wheel Works, Buffalo, New York, moulding machines are installed, and the handling of the moulds is accomplished by a moving platform, composed of a number of cars, each car carrying a mould. This platform remains

stationary during pouring, and then advances one car-length at a time automatically. Details of operation are given.

E. Longden, *Moulding Slag Ladles* (Foundry Trade Journal, October 6, 1921, vol. 24, pp. 271-272). The method of moulding ladles in loam is described.

Large Cores for Turbine Castings (Iron Age, July 28, 1921, vol. 108, pp. 202-203). The methods employed in producing cores for castings for steam turbines are described and illustrated.

Special Castings.—H. E. Diller, *Making Rolls for Steel Mills* (Iron Trade Review, August 18, September 1, 1921, vol. 69, pp. 419-424, 432, 547-554; Foundry Trade Journal, September 1, 1921, vol. 24, pp. 167-170). The manufacture of steel and chilled iron rolls is described at length.

A. Dat, *Casting in Chills* (Arts et Metiers, June 1921, vol. 74, pp. 167-170). Contains directions for the design of chills and for carrying out the operations of casting.

J. J. Zimmerman, *Casting Large Pipe Fittings* (Blast-Furnace and Steel Plant, July 1921, vol. 9, pp. 417-420). The casting and moulding of large cast iron elbows is described and illustrated.

Malleable Castings.—H. A. Schwartz, *American Malleable Cast Iron* (Iron Trade Review, May 12, 26, June 16, 30, July 14, 28, August 11, 25, September 8, 29, 1921, vol. 68, pp. 1317-1321, 1453-1460, 1662-1668, 1792-1797; vol. 69, pp. 98-101, 233-238, 354-359, 371, 496-499, 611-616, 626, 813-816). The continuation of a series of articles dealing with the development of the malleable cast iron industry of the United States. Raw materials, fuels and refractories, air-furnace, electric furnace, cupola and open-hearth melting practice, annealing, patternmaking and moulding, and cleaning and finishing of malleable iron castings are dealt with in the above-mentioned articles.

C. Kluytmans, *French Malleable Cast Iron* (Fonderie Moderne, August 1921; Foundry Trade Journal, May 19, 1921, vol. 23, pp. 447-449). The European method of producing malleable cast iron is described.

R. Stotz, *Properties and Uses of Malleable Castings* (Betrieb, July 10, 1921, pp. 631-636). Practice in the production of malleable castings is described, and the various purposes are indicated for which its properties render it adaptable.

Foundry Equipment.—*The Kryn and Laby Works, Letchworth* (Iron and Coal Trades Review, May 27, 1921, vol. 102, pp. 719). The equipment of this steel foundry is briefly described. The melting plant consists of six Tropenas converters each of a capacity of 25 cwt., and one 30-cwt. Electro-Metals electric furnace. The output of the foundry is approximately 600 to 800 tons of steel castings per month.

New Ford Foundry (Iron Trade Review, September 22, 1921,

vol. 69, pp. 739-746). An illustrated description is given of the new foundry of the Ford Motor Co., at River Rouge, Michigan.

L. B. Breedlove, *New Ford Foundry Plant at River Rouge* (Iron Age, September 29, 1921, vol. 108, pp. 787-798). The lay-out of this plant is described and illustrated. There are twenty-four cupolas in operation, and direct metal is used for mixing with the cupola metal in definite proportions as required.

H. M. Lane, *Continuous Foundry for Pipe Fittings* (Iron Age, September 1, 1921, vol. 108, pp. 519-524). The plant and practice at an American foundry for the production of pipe fittings is illustrated and described.

Steel Foundry has Special Operating Features (Iron Age, October 20, 1921, vol. 108, pp. 991-995). The lay-out and the equipment of the plant of the National Steel Foundries, Milwaukee, is described and illustrated.

PRODUCTION OF STEEL.

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I.—PROCESSES OF STEEL PRODUCTION.

Steel Furnace Construction.—P. S. Young, *The McKune System for Open-Hearth* (Blast-Furnace and Steel Plant, June 1921, vol. 9, pp. 371–374). The McKune system of open-hearth furnace ports is described. See abstract, *Journal*, 1921, No. I. p. 418.

A. G. Schumann and A. F. Schumann, *Improvement in Open-Hearth Details* (Iron Age, August 4, 1921, vol. 108, pp. 269–272). A new automatic reversing valve, and an oil and tar burner developed by the authors and fitted to the open-hearth furnaces at the Sparrows Point plant of the Bethlehem Steel Corporation are described and illustrated. The diagrammatic plan of the arrangement of valves and mechanism shows that these are controlled by a clock-work, which reverses the furnace valves every fifteen or twenty minutes by means of solenoids, actuating a four-way valve controlling the steam supply to a long cylinder, which moves the furnace valves. When the furnace is oil fired, and the burners are in use, the same mechanism which reverses the valves also pulls back the operating burner into its cooler, and at the same time shifts into position the burner at the other end of the furnace.

A. D. Williams, *Open-Hearth Furnace Design* (Iron Age, September 22, 1921, vol. 108, pp. 719–721). The effect of reversing valves on the efficiency of the open-hearth furnace is discussed.

W. H. Wharton, *New Controlling Valve for Open Hearths* (Blast-Furnace and Steel Plant, April 1921, vol. 9, pp. 253, 280). A description is given of a new type of reversing valve devised by the author, which operates in conjunction with air-pressure and volume-controlling mechanism.

G. L. Prentiss, *A Radical Change in Open-Hearth Practice* (Iron Age, June 2, 1921, vol. 107, pp. 1479–1481; Iron Trade Review, June 9, 1921, vol. 68, pp. 1586–1587). An illustrated description is given of the arrangement of the ports in the Egler open-hearth furnace in operation at the plant of the Brier Hill Steel Co., Youngstown, Ohio. In producer-gas fired furnace practice the air is put in to the checker

chamber by fan pressure, the gas being fed at the natural producer pressure. The gas comes up under the port hood at the end farthest from the hearth and is turned and directed downward toward it in the usual way. At the proper point in its flow toward the hearth the gas meets a stream of air fed vertically upward and across the stream of gas. The torch of air and gas rushes from the port nozzle in a perfectly mixed flame and the air on the under side of the gas appears to draw the flame down and hug the surface of the bath. The roof is bathed in a slow moving body of air, the surplus over that needed for combustion. At each end of the furnace are two flues auxiliary to the main air and gas supply. These flues at the upper or furnace end of their intakes are fitted with water-cooled mushroom valves on water-cooled seats. At the end where the gas is entering these valves are tightly closed, and the flues they cover (which are filled with air from the air regenerators) cannot discharge into the furnace. At the discharge end of the furnace these auxiliary valves are wide open and the valves themselves are drawn up in pockets provided in the furnace roof. These flues thus uncovered permit the gases of combustion, now greatly expanded, to flow from the furnace to the regenerators. This furnace can be adapted to all kinds of gas and liquid fuel. For the use of coke-oven gas or natural gas the installation differs slightly from that for use with producer-gas.

Steel-Making Practice.—Y. W. Aubel, *Use of Cupolas in Open-Hearth Practice* (Iron Age, August 18, 1921, vol. 108, pp. 403-405). The melting of high silicon pig iron for supplying basic open-hearth furnaces is described. The practice and costs of operation are given. The advisability of using cupolas to premelt in plants having no blast-furnaces depends so much on local conditions that it could not be advocated as a general rule. The author believes that, with a modern mechanically charged cupola, the increased production of the open-hearth furnace from the use of hot metal will considerably more than pay for the cost of operating such a cupola plant.

H. W. Seldon, *Heat Transfer in Open-Hearth Furnaces* (Blast-Furnace and Steel Plant, May, July 1921, vol. 9, pp. 299-304, 422-423). The author presents some considerations regarding the manner in which heat is transferred from the flame to the bath in an open-hearth furnace. The article is based mainly on the work of Houbaer, published in the *Journal of the Iron and Steel Institute* in 1913, and from the reports on "Fuel Economy" published in 1919.

Cosmo Johns, *The Surface of Liquid Steel* (Paper read before Section B of the British Association, September 1921). The question dealt with was, Why liquid steel at a temperature of 1600° C. was able to preserve its surface unoxidised? The author pointed out that this was specially noticeable in steel as it flowed from the furnace into the ladle. He succeeded in getting some samples of the greenish fume found floating above the metal, and found that if the analysis of this

vapour was recalculated on an oxygen-free basis it differed in no marked degree from the original steel as regards chemical constitution. Taking a metal containing manganese, nickel and chromium, he found that the ratio of the steel from the fume recalculated to the original steel was manganese 1:3, chromium 1:1.25, and nickel 1:0.67, which proved that the fume really did represent the condensed vapour of the steel and contained some of the metal in the original steel.

J. Dupuis, *Use of Coke-Oven Gas in Heating Open-Hearth Furnaces* (Revue de l'Industrie Minérale, Mémoires, October 15, 1291, pp. 627-633). Experiments have shown that open-hearth furnaces can be heated by gas made from coke in producers, but that the results are unsatisfactory and operations are slowed down. Coke-oven gas, on the other hand, by its richness and higher calorific value, is an ideal fuel, either used by itself or with admixture of blast-furnace gases. It is a mistake, however, to suppose that with the ordinary furnace design, and with regenerators, ports and valves meant for use with ordinary producer-gas, coke-oven gas can be directly and successfully employed so as to reap the advantages it offers. The structural requirements are different when the richer gas is used, and this should be borne in mind and the necessary alterations made to secure the best results. For instance, it is not necessary to reheat the richer gas, which can yield all the required temperature in its ordinary state, and in far smaller volumes when used alone than when a poorer gas is employed. Only the air need be heated, and thus two regenerative chambers only are required instead of four. As, however, the rich coke-oven gases can often be more economically used elsewhere, the solution of their employment for open-hearth furnaces would seem to lie in the direction of their dilution with poorer gas, but here again the necessary structural alterations which theory suggests must be made before success is attained. At the Saint Jacques works at Montluçon excellent results have been obtained by using a mixture containing 80 per cent. of producer-gas from coke-fired producers with 20 per cent. of coke-oven gas. The function of the water vapour present is important, as it helps to prevent carbon deposition.

F. Boettcher, *Firing of Open-Hearth Furnaces with a Mixture of Brown-Coal Producer-Gas and Blast-Furnace Gas* (Stahl und Eisen, July 28, 1921, vol. 41, pp. 1027-1030). An installation of four open-hearth furnaces is heated with producer-gas from brown-coal briquettes mixed with blast-furnace gas in the average proportion of 50.7 to 49.3, the brown-coal gas having a mean calorific value of 1650 calories, and the blast-furnace gas 1000 calories. Calculations show that the total heat used is equivalent to a consumption of 238 kilogrammes of ordinary coal, or 376 kilogrammes of brown-coal briquettes per ton of steel produced. For successful working the gas-producers must be worked slowly, at about the rate of not more than 10 tons of briquettes per twenty-four hours in a producer with a grate diameter of 10 feet.

P. B. Brace, *Notes on the Metallurgy of Calcium* (Journal of the Institute of Metals, No. 1, 1921, pp. 153-174). Notes amongst the experimental applications of calcium, that it and its light alloys have been used as a filling for light hollow structural steel, and that it has likewise been found to destroy welding properties. It also desulphurises molten low carbon iron, but has little effect on the phosphorus content.

O. Holz, *The Relation between the Physical and Chemical Character of Basic Pig Iron* (Stahl und Eisen, September 15, 1921, vol. 41, pp. 1285-1293). The time of the blow in the basic converter is considerably increased if the pig iron drawn from the mixer contains over 1.4 per cent. manganese and 0.3 per cent. silicon owing to the pig iron becoming more thick fluid, as these elements, especially the silicon, are increased. To make the iron more fluid and to shorten the blow, the author recommends that the mixer iron should first be passed through an open-hearth furnace, remaining there for ten to fifteen minutes until it is overheated. This reduces the phosphorus somewhat, but does not render the iron chemically unsuitable for the basic converter. The various economies which can be obtained by this means are estimated to amount to 20 marks per ton of steel.

H. D. Hibbard, *Control of Temperature in the Acid Bessemer Blow* (Blast-Furnace and Steel Plant, May 1921, vol. 9, pp. 287-290). The methods of raising and lowering the temperature in acid Bessemer practice are summarised.

E. Herzog, *Behaviour of the Sulphur in the Basic Converter* (Stahl und Eisen, June 9, 1921, vol. 41, pp. 781-788).

O. von Keil, *Deoxidation in the Basic Bessemer Process* (Stahl und Eisen, May 5, 1921, vol. 41, pp. 605-611).

Electric Steel Furnace Practice.—L. J. Barton, *Electric Furnace Operating Experiences* (Iron Age, September 8, 1921, vol. 108, pp. 581-584). The operation of a 6-ton basic-lined Heroult furnace is discussed. It is recommended that the bottom should be saucer-shaped and of dead burned magnesite, and the walls of silica brick 9 inches thick. The electrodes should be of amorphous carbon 17 inches in diameter.

M. H. Schmid, *Operating Records of Electric Furnaces Refining High-Grade Steels* (Electrical World, 1921, vol. 77, p. 605). The average figures are given for a twelvemonth's performance with an installation of two 15-ton and one 6-ton three-phase Heroult furnaces, and two 1-ton single-phase Snyder furnaces. The 6-ton Heroult furnaces require 568 kilowatt-hours per ton for melting and refining cold scrap and the 15-ton furnaces 168 kilowatt-hours when the charge is already molten. The electrode consumption is 26.6 lbs. per ton of steel. The Snyder furnaces require 1002 kilowatt-hours to melt and refine cold metal, the electrode consumption being 41.4 lbs. per ton.

W. J. Stuart Green and S. Stuart Green, *Electric Furnace Tool Steel Qualities* (Iron Age, September 15, October 27, 1921, vol. 108,

pp. 669-671, 1061-1064). The proper selection of melting stock and the standardisation of melting practice in basic furnace practice is discussed

E. T. Moore, *Electric Furnace Progress in 1921* (Iron Age, September 23, 1921, vol. 108, pp. 723-724). The merits of dual voltages for melting and refining are discussed.

Decreasing Electrode Consumption in Electric Furnace (Electrical World, 1921, vol. 77, p. 776). Wasteful oxidation occurring in the furnace is due to the evolution of oxidising gases from the charge. This can be reduced by covering the electrode with non-burning paint, or surrounding the electrode with steel or water-cooled collars.

E. Dieudonné, *The Arc Furnace in the Manufacture of Steel* (Age de Fer, May 20, 1921, vol. 37, pp. 1026-1028). The heat balance and methods of operating arc furnaces are discussed.

Electric Furnaces of Special Type.—A. Stansfield, *Electric Furnaces for Making Steel* (Blast-Furnace and Steel Plant, March-August, 1921, vol. 9, pp. 189-193, 263-266, 324-327, 381-385, 424-425, 488-489). The design and operation of electric furnaces for steel-making is discussed, and various types of furnaces are described and illustrated.

New Type of Induction Electric Furnace (Iron Age, August 11, 1921, vol. 108, pp. 344-346). In this furnace the primary winding is situated above the bath. The crucible is of simple ring form, giving substantially constant cross-section for the charge, which is accessible by means of two or more lateral doors. The rammed lining is made up of a basic material known as furnite. A 2-ton furnace of this type has been in operation at the Pittsfield Works of the General Electric Co. for over a year. The general design of the furnace is illustrated.

H. Nathusius, *The Nathusius Electric Furnace* (Engineering Progress, June 1921: Foundry Trade Journal, July 28, 1921, vol. 24, pp. 71-72). This type of furnace represents a combination of an arc furnace and a resistance furnace. (See also this Journal, 1912, No. I. p. 51.)

J. B. C. Kershaw, *The Electric Furnace in Melting and Refining* (Electrician, November 18, 1921, vol. 87, pp. 636-639). The development in the design of electric furnaces is discussed, and several types are described.

Steelworks Equipment in Various Countries.—S. G. Koon, *Plant of the Erie Forge and Steel Co.* (Iron Age, June 16, 1921, vol. 107, pp. 1595-1603). The equipment of this plant includes two 60-ton basic open-hearth furnaces and two hydraulic presses of 2000 and 1500 capacity. Oil fuel is used for melting the charge and making the heat. All the ingots are top poured, and are kept hot by means of a hot-top casting lined with refractory material. The riser of the ingot comes up into the hollow casting to a pre-determined height.

Hence the hot top within the mould and upon the liquid ingot floats upon the metal and follows it down as it shrinks in solidifying. This insures a sound top.

The Steelworks of Czecho-Slovakia (American Machinist, European and Colonial edition, July 2, 1921, vol. 54, pp. 826-828). A brief illustrated account is given of the plant of the Poldi Steel Works.

French Iron and Steel Works (Iron and Coal Trades Review, September 9, 1921, vol. 103, pp. 339-347). In connection with the Autumn Meeting of the Iron and Steel Institute in France, particulars are given of the equipment of the following plants: Les Petits-Fils de François de Wendel; Hagondange Steel Works; Rombas Steel Works; the Homécourt Works; the Pont-à-Mousson blast-furnaces and foundries; the Creusot Works, and the Works of the Société Normande de Métallurgie.

Rotary Kiln Lime-Burning Plant (Blast-Furnace and Steel Plant, August 1921, vol. 9, pp. 467-468). A brief description of the lime-burning plant at the Granite City Steel Works, Illinois. There are two rotary kilns in operation for supplying lime to the open-hearth furnaces.

II.—CASTING AND TREATMENT OF INGOTS.

H. D. Hibbard, *Leaves from a Steel Melter's Notebook* (Iron Age, October 27, 1921, vol. 108, pp. 1065-1067). The author relates his experiences in the making of hollow steel ingots for the manufacture of seamless pipe.

A. Brüninghaus and F. Heinrich, *Piping and Segregation in Siliconised Ingots* (Stahl und Eisen, April 14, 1921, vol. 41, pp. 497-509). An investigation of various methods for improving the soundness of steel.

F. Pacher, *Transverse Dimensions of Steel Ingots for Forging* (Stahl und Eisen, July 7, 1921, vol. 41, pp. 913-919). The most suitable form and size of the cross-section of steel ingots for large forgings are considered.

FORGING AND ROLLING-MILL PRACTICE.

Forging Practice.—F. B. Fairbanks, *Drop Forgings Replace Steel Castings* (Forging and Heat Treating, April 1921, vol. 7, pp. 214–215). The advantages of drop forgings are discussed. It is claimed that they are of superior strength, toughness, and resistance to shock and wear, and can be produced at a lower cost than steel castings.

F. B. Jacobs, *Modern Methods Facilitate Axe Manufacturing* (Iron Trade Review, September 22, 1921, vol. 69, pp. 747–752). The operations involved in the forging and grinding of axes are described.

Producing a Stamped Shift Lever Dome (Iron Age, June 2, 1921, vol. 107, pp. 1441–1444). An illustrated description is given of the nine distinct operations involved in the stamping of lever domes. Only one annealing is necessary. The steel used is hot-rolled strip $5\frac{1}{8}$ inches in width, of good drawing quality, pickled and oiled.

G. A. Richardson, *An Improved Method of Making Steel Gear and Wheel Blanks* (American Machinist, European and Colonial edition, July 30, 1921, vol. 54, pp. 981–984). The blanks are produced by a combined rolling and pressing operation, by means of two dies, one mounted at the end of an hydraulic ram, and the other mounted on a shaft driven by an electric motor. The rolling action is produced by having the latter die placed with its axis of rotation at a small angle to the other die.

Rolling-Mill Equipment.—L. Rothera, *The Future of Electrically-Driven Rolling-Mills* (Electrician, November 18, 1921, vol. 87, pp. 632–633). The successful future of the electrically-driven mill is assured, apart from its inherent advantages, by the great advance that has been made in the efficiency of power generation since the earlier installations.

Motor Equipment for Main Drive of Rolling-Mills (Electrician, November 18, 1921, vol. 87, pp. 647–653). A list is given of electrically-driven rolling-mills in operation and in course of erection in the United Kingdom, showing type of mill, horse-power and speed, nature of energy, and drive.

K. A. Pauly, *Some Methods of obtaining Adjustable Speed with Electrically-Driven Mills* (Proceedings of the Engineers' Society of Western Pennsylvania, 1921, vol. 37, pp. 158–188). Some of the more important considerations which affect the speed of rolling, and

the different systems of obtaining the required speed control are discussed.

French Rolling-Mills (Iron Trade Review, August 25, 1921, vol. 69, pp. 480-483). An illustrated description is given of the new rolling-mill plant to be installed at the Homécourt Works of the Compagnie des Forges et Aciéries de la Marine et d'Homécourt.

G. L. Lacher, *Milwaukee Sheet Mill* (Iron Age, June 23, 1921, vol. 107, pp. 1681-1685). The lay-out of the plant of the Milwaukee Rolling-Mill Co. is described and illustrated. There are four roughing stands, two in each of the duplicate trains of four hot mills. Each train is driven at thirty revolutions per minute, through gears from a 1000 horse-power induction motor, operating at 300 revolutions per minute. The two roughing mills in each train are arranged on either side of the motor. Next to each roughing mill are two finishing mills, while at each end of the train is a stand of cold rolls. Thus each half of the train is the converse of the other.

G. H. Manlove, *Western Sheet Mill* (Iron Trade Review, June 23, 1921, vol. 68, pp. 1715-1719). The new rolling-mill plant of the Milwaukee Rolling-Mill Co., Milwaukee, is illustrated and described. The sheet mills are built in two units of four mills each, consisting of two stands of cold rolls, four stands of finishing rolls, and two stands of roughing rolls. Each unit is driven by a 1000 horse-power motor.

E. F. Ross, *Sheet Mill in Indiana* (Iron Trade Review, June 16, 1921, vol. 68, pp. 1651-1656). The lay-out and equipment, comprising modern sheet mills and galvanising plant, of the Chapman Price Steel Co., Indianapolis, is described and illustrated.

E. C. Kreutzberg, *New Sheet Mill* (Iron Trade Review, July 14, 1921, vol. 69, pp. 89-91). The new rolling-mill plant of the Eastern Rolling-Mill Co. is illustrated and described. It has a capacity of 70,000 tons of sheets per annum.

Sheet Rolling-Mills at Baltimore (Iron Age, June 9, 1921, vol. 107, pp. 1535-1538). An illustrated description of the sheet mills of the Eastern Rolling-Mills Co., Baltimore. The equipment includes twelve finishing hot mills, eight stands of roughing mills and twenty stands of cold rolls. All the mills are electrically driven.

Whitaker-Glessner Continuous Mill (Iron Age, June 30, 1921, vol. 107, pp. 1747-1749). The new mill recently put into operation at the Portsmouth plant of the Whitaker-Glessner Co. is claimed to be one of the most modern continuous mills in the United States. It consists of six stands of 18-in. roughing and finishing rolls together with two edging mills, situated respectively before the first and third roughing passes. Provision is made for drawing loops between each pass when rolling sheet bars; and by use of the edging rolls, 10-lb. sheet bars may be rolled, with good edges and of accurate weight, from slabs 12 inches wide and $2\frac{1}{2}$ inches thick, without having to use tongue and groove passes. The shoes are arranged so that each mill

may be lifted off separately and replaced with rolls assembled—ready for rolling blooms 4 inches square to billets $1\frac{1}{2}$ inches square—twisting guides being placed between each alternate pair of rolls.

G. H. Manlove, *Mill for Alloy Steel* (Iron Trade Review, October 6, 1921, vol. 69, pp. 869–873, 880). The rolling-mill plant of the Interstate Iron and Steel Co., South Chicago, for rolling alloy steel is described and illustrated.

G. L. Lacher, *New Interstate Mill* (Iron Age, October 6, 1921, vol. 108, pp. 859–864).

S. G. Koon, *Government Armour Plate Factory* (Iron Age, May 26, 1921, vol. 107, pp. 1365–1371). The equipment of the Naval Ordnance plant at South Charleston, West Virginia, is described, and the improvements carried out since its formation in 1897 are noted.

Electricity and Tube, Tyre, and Wheel Mills (Electrician, November 18, 1921, vol. 87, pp. 654–655). The problems involved in the electric driving of tube, tire, and wheel mills is discussed.

Manipulator for Rolling-Mills (Iron and Coal Trades Review, June 3, 1921, vol. 102, p. 762). An illustrated description is given of the Williams patent manipulator for handling material through rolling-mills.

G. F. Paul, *Electromagnets in a Plate Cooling Bed* (Iron Age, August 11, 1921, vol. 108, pp. 321–323). The method of handling rolled steel sheets on the cooling beds, by means of electromagnetic skids, at the Redcar Works of Dorman, Long & Co., Ltd., is described.

W. F. Osborne, *Lubrication of Gears and Pinions* (Blast-Furnace and Steel Plant, August 1921, vol. 9, pp. 470–471). The efficient lubrication of steel mill drives is discussed.

Rolling-Mill Practice.—G. E. Stoltz, *Cost of Rolling Steel in Blooming Mills* (Paper read before the Association of Iron and Steel Electrical Engineers: Iron Age, October 20, 1921, vol. 108, pp. 998–1000). Figures are given showing the costs of operating steam- and electric-driven blooming-mills. The comparison favours the electric-driven mill.

S. G. Koon, *Rerolling Rails at Sweets Steel Co.* (Iron Age, May 12, 1921, vol. 107, pp. 1227–1232). At the plant of this Company, at Williamsport, Pa., rails are heated to a rolling temperature in a continuous furnace and rolled down into smaller sections with a reduction to 20 or 25 per cent. of original weight per yard, or are split in three parts, head, web, and flange, and these parts are then separately rolled into angles, concrete bars, splice plates, steel dies, and fence posts. Details of the operations involved are illustrated and described.

J. D. Knox, *Rerolling Discarded Steel Rails* (Iron Trade Review, July 28, 1921, vol. 69, pp. 226–231). The practice at the plant of the Sweets Steel Co. is described and illustrated.

J. D. Knox, *Rerolling Rails in New Ohio Mill* (Iron Trade Review, May 19, 1921, vol. 68, pp. 1384-1387). An illustrated description is given of the equipment of the plant of Cambridge Steel Co., Ohio, for the rerolling of old rails into merchant and special shapes.

Rolling-Mill Repairs.—F. E. Rogers, *Reclaiming Worn Wobblers by Welding* (Iron Trade Review, May 26, 1921, vol. 68, pp. 1450-1451). The worn parts are first preheated, and then built up by the oxy-acetylene process.

FURTHER TREATMENT OF IRON AND STEEL.

Pyrometry.—R. S. Whipple, *Difficulties of Maintaining a Pyrometer Installation in a Works* (Paper read before Refractory Materials Section of the Ceramic Society, May 14, 1921). The types of pyrometer most generally suitable for industrial purposes are the following: the resistance thermometer, for low temperatures up to 700° C.; the thermo-electric thermometer, for temperatures from 0° C. to 2000° C.; and the optical or radiation pyrometer, for temperatures from 700° C. to 2000° C. The causes affecting the accuracy of pyrometers are considered and suggestions for their protection and maintenance are put forward.

E. Wetzel, *Measurement of Temperature in the Metal Industries* (Zeitschrift für Metallkunde, May-June 1921, vol. 13, pp. 234-236, 286-289). The various methods in ordinary use for measuring temperatures in metallurgical operations are critically reviewed, and different types of pyrometers are described.

H. G. Hall, *The Essentials of Modern Pyrometer Equipment* (Transactions of the American Society for Steel Treating, June 1921, vol. 1, pp. 505-511).

P. D. Foote, C. O. Fairchild, and T. R. Harrison, *Pyrometric Practice* (United States Bureau of Standards, Technologic Paper No. 170). The practical application, standardisation, and design of modern American pyrometers is discussed.

P. D. Merica, *Calculations of Equilibrium in Metallurgical Reactions* (Chemical and Metallurgical Engineering, September 28, 1921, vol. 25, pp. 608-612). Discusses the value in metallurgical researches of thermochemical considerations frequently employed by physicists and comparatively ignored by metallurgists, such as relative stability, oxidation and reduction, and equilibrium conditions.

Case-Hardening.—F. Giolitti, *Case-Hardening and Oxidation of Steel* (Chemical and Metallurgical Engineering, August 24, 1921, vol. 25, pp. 312-313). A criticism of Matsubara's views on the chemical equilibrium between iron, carbon, and oxygen. At certain temperatures the simultaneous carbonisation and oxidation of iron can only take place when the pressure of the C:CO:CO₂ system exceeds a certain value. Hence it follows that the curves corresponding with the two reactions must cross each other at that pressure.

L. Guillet, J. Galibourg, and P. Beuret, *Grinding Cracks* (Revue

de Métallurgie, Mémoires, April 1921, vol. 18, pp. 213-220). In the case of the surface cracking of case-hardened parts, such cracks are very frequently due not to wrong heat treatment but to local heating, quenching, and annealing under the action of the emery-wheel, and the water used for cooling. Experimental evidence of the operation of these causes is given. The conclusions are reached that such cracks are not primarily due either to the thickness of the case, interstrain, or the pressure of an excess of cementite, but to local heating, and this was proved by such cracks being developed, independently of grinding operations, by the simple process of heating and suddenly cooling the parts. In order to avoid such cracks resulting from grinding, a high rate of rotational speed should be imparted to the metal, so that the local over-heating may not have long enough to produce martensite-sorbite changes, and this rate of speed should be adjusted to the relative amounts of surface in contact between the piece and the grinding appliance. If, owing to planeness in the latter, contact is shortened a lower rate of rotation can be adopted. With concavities in the grinding appliance, contact is longer and the rate of rotations should be more rapid to avoid the consequences of the local heating.

S. C. Spaulding, *A Comparison of the Rate of Penetration of Carbon into Various Commercial Steels in Use for Case Carbonising* (Paper read before the American Society for Steel Treating, September 30, 1921). The steels investigated comprised plain carbon, chrome-silicon-manganese, chrome-vanadium, nickel, chrome-nickel, and chrome-molybdenum steels. The results indicate the superiority of the chrome-nickel and chrome-molybdenum steels in so far as rate of penetration of carbon is concerned. The difference between cold-rolled and hot-rolled straight carbon steels shows the retarding effects of high phosphorus and high sulphur.

H. Schagrin, *Carbonisation with Wood Charcoal* (Paper read before the American Society for Steel Treating, September 20, 1921). Experiments were carried out on acid Bessemer forgings, to determine the amount of penetration that takes place at 1400° and 1500°, and at the high temperature of 2000° F. Photomicrographs show that carburisation begins at 1450°, after being in the furnace 1½ hours, and at 1950° it was possible to secure a penetration of $\frac{1}{16}$ th of an inch for about 1½ to 2 hours carburising period.

L. Aitchison, *Some Fallacies about Case-Hardening* (Paper read before the Birmingham Metallurgical Society, May 19, 1921: Iron and Coal Trades Review, May 27, 1921, vol. 102, p. 728). The author discusses the influence of the strength of the core upon the conditions which produce fracture of the case.

A. A. Blue, *Carbonising Manganese Steel* (Forging and Heat Treating, August 1921, vol. 7, pp. 413-415). Contrary to the usual belief that high manganese steels are not suitable for case-hardening, the author states that the increased manganese content produces greater sensitivity to carburising.

C. Kluytmans, *Some Notes on Case-Hardening* (Foundry Trade Journal, July 14, 1921, vol. 24, pp. 29-34). The results are given of an investigation of the case-hardening properties of carbon, nickel, and nickel-chromium steels.

H. B. Knowlton, *Carbonising and Carbonising Materials* (Transactions of the American Society for Steel Treating, August 1921, vol. 1, pp. 689-698). The requirements of case-hardening compounds are discussed.

T. G. Selleck, *First Principles of the Carbonising Process: A Consideration of the Fundamental Facts and Factors* (Transactions of the American Society for Steel Treating, April 1921, vol. 1, pp. 383-397).

C. M. Campbell, *Alloy Carbonising Boxes* (Paper read before the American Society for Steel Treating, September 20, 1921). The author considers some of the factors governing the life and performance of carburising boxes.

Reheating and Annealing Furnaces.—W. Trinks, *Heating and Annealing Furnaces* (Blast-Furnace and Steel Plant, April-June 1921, vol. 9, pp. 267-272, 305-308, 377-381). The continuation of a series of articles on the design and operation of heating furnaces. A comparison is made of the different types of sheet furnaces.

H. Illies, *Equipment of Heating and Annealing Furnaces* (Stahl und Eisen, April 21, May 5, 12, 1921, vol. 41, pp. 533-538, 617-624, 648-656). The article describes and illustrates fully the machinery for handling ingots, blooms, billets, forgings, and charging appliances in general use for serving reheating furnaces.

Gas-Fired Annealing Furnace (Iron and Coal Trades Review, July 22, 1921, vol. 103, p. 107). Particulars are given of the new annealing furnace installed at Guest, Keen & Nettlefolds, Ltd., St. George's Works, Smethwick. The plant is the first of its type to be put under gas in this country, and consists of two self-contained twin pot rotary flame annealing furnaces of the Chantaine type. A test of 127 hours' duration was recently carried out on this furnace, and during this period 125½ tons of furnace contents were heated to an average temperature of 800° C. with a total consumption of 11,149 lbs. of coal of producer-nut quality. This works out at approximately 88½ lbs. of coal per ton of furnace contents.

G. Keillor, *Gaseous Fuels in the Shipbuilding World* (Paper read before the British Commercial Gas Association: Iron and Coal Trades Review, September 30, 1921, vol. 103, pp. 476-478). The author deals with the use of gas-fired furnaces for heat-treating operations in shipbuilding, and the method of drying foundry cores and moulds by means of gas. Tables are given showing the working results obtained under ordinary commercial conditions with the "Revergen" furnace employed in annealing, hardening, and normalising of castings, and also with rivet heating furnaces and forge furnaces.

F. F. Cauley, *The Value of Gas for Heat Treatment* (Paper read before the American Gas Association, June 1921, vol. 7, pp. 328-331). The application and value of gas for heat treatment and allied operations is discussed, and various modern installations are illustrated.

S. Trood, *Furnaces for Heat Treatment of Die Blocks* (Paper read before the American Drop Forge Convention, June 24, 1921: Forging and Heat Treating, July 1921, vol. 7, pp. 393-397). Temperature control in the treatment of die blocks is discussed, and the Tate-Jones furnace is described.

G. L. Lacher, *Automatic Heat Treating Furnaces* (Iron Age, June 30, 1921, vol. 107, pp. 1754-1755). A type of automatic electric heat-treating furnace is described. Electric motors, actuated by a time-clock mechanism, raise and lower the furnace doors, advance the material through the furnace and quench it, making it unnecessary to have any conveying mechanism within the hot zone of the furnace. The heating principle is very simple. Carborundum troughs are placed lengthwise on either side of the furnace hearth; these troughs are connected outside the furnace to special oil switches, and these in turn connected to the transformer taps corresponding with the power input and temperature desired.

Closing a switch passes a low voltage current through the carbon in the trough and quickly brings it to incandescence. The heat thus generated is radiated from the bottom of the trough underneath the elevated hearth, from its sides direct to the hearth, and from the top of the trough to the roof and thence reflected to the hearth. This results in a large source of relatively low temperature heat, uniformly distributed throughout the furnace.

A. D. Dauch, *Rotary Furnace for Automobile Parts* (Iron Age, September 15, 1921, vol. 108, pp. 666-667). The operation of an electrically operated rotary furnace with a moving hearth in the form of a continuous annular ring for the heat treatment of automobile parts is described and illustrated.

E. F. Cone, *Electric Furnaces and Heat Treatment* (Iron Age, September 15, 1921, vol. 108, pp. 643-648). A survey of the application of electric furnaces to the heat treatment of steel. A list is given of the installations in the United States.

E. F. Collins, *Electric Furnace for Heat Treatment* (Paper read before the American Drop Forge Association, June 24, 1921: Iron Age, August 4, 1921, vol. 108, pp. 266-267). The use of electric furnaces for the heat treatment of drop forgings is discussed. The furnaces are usually of the metallic resistor type, operating up to about 1800° F. The operating results of an electric furnace compared with an oil-fired furnace are given.

E. F. Collins, *Relative Thermal Economy of Electric and Fuel-Fired Furnaces* (Transactions of American Society for Steel Treating, January 1921, vol. 1, pp. 217). Contains a table showing fuel heat losses

and cost per 100,000 B.Th.U.'s, of coke, coal, gas, fuel oil, anthracite, bituminous coal, and natural gas fired furnaces, as compared with electric furnaces.

S. A. Moulton and W. H. Lyman, *Relative Economy of Oil, Gas, Coal, and Electric Heated Furnaces* (Transactions of the American Society for Steel Treating, January 1921, vol. 1, pp. 249-270).

W. F. Hoernke, *Annealing Malleable with Fuel Oil* (Iron Trade Review, June 23, 1921, vol. 68, pp. 1728-1730). The application of fuel oil for the annealing of malleable cast iron is dealt with.

Heat Treatment of Steel.—L. Aitchison, *Volume Changes in the Heat Treatment of Steel* (Transactions of the American Society for Steel Treating, September 1921, vol. 1, pp. 734-737). Deals with the stresses which occur as the result of variable volume changes in any given piece of steel during heat treatment.

W. Tafel, *Occurrence of Stresses due to Heat Treatment* (Stahl und Eisen, September 22, vol. 41, pp. 1321-1328). It is shown that changes in the internal stresses of any piece of steel are produced by heat treatment, whether the piece is of spherical, prismatic, or cylindrical form. The principal changes in form which occur due to hardening are indicated, and some practical points to observe in the annealing and hardening of steel are noted.

M. A. Grossman, *The Toughness of High-Speed Steels as affected by their Heat Treatment* (Paper read before the American Society for Steel Treating, September 22, 1921). The author has found that there is a certain quenching temperature slightly below the proper hardening range for which the steel is brittle on being quenched and acquires no toughness on being drawn up to 1100° F. Below this quenching range, drawing imparts toughness but lowers the hardness. Above that range drawing at 1100° imparts toughness while at the same time developing secondary hardness.

D. M. Giltinan, *The Metallurgy of High-Speed Steel* (Transactions of the American Society for Steel Treating, September 1921, vol. 1, pp. 716-726). Traces the progress made since the discovery of high-speed tool steels and gives an interesting table showing the compositions of such tools in their chronological sequence of development. The employment of uranium is foreshadowed, and a reference is made to the use of cobalt as a substitute for tungsten, and to a new nickel-aluminium-silicon-zirconium alloy similar to steel, recently made in America. A theory of self-hardening, combining the views of Osmond and of Carpenter is suggested, and the view taken that chromium and tungsten lower the carbon content of pearlite, thus accounting for an excess of free carbides seen in annealed high-speed steel with 0.60 to 0.70 per cent. of carbon.

A. J. Wilson, *High-Speed Steel* (*Ibid.*, May 1921, vol. 1, pp. 436-440). The heat treatment of high-speed tools, and the grinding and re-use of worn tools is discussed.

A. E. Bellis, *Heating and Quenching High-Speed Steel* (Transactions of the American Society for Steel Treating, May 1921, vol. 1, pp. 441-445).

G. Porteous, *High Carbon Open-Hearth Steel versus Crucible Tool Steel in the Manufacture of Miscellaneous Tools* (Transactions of the American Society for Steel Treating, January 1921, vol. 1, pp. 238-244). The use of high carbon open-hearth steel for the manufacture of chisels and punches is discussed. The grade of steel that has proved most successful has an analysis of approximately 0.8 to 1 per cent. of carbon, less than 0.03 phosphorus, less than 0.03 sulphur and 0.35 to 0.45 per cent. manganese. The proper heat treatment is outlined.

G. H. Gilman, *Heat Treatment of Rock-Drill Steel* (Paper read before the American Institute of Mining and Metallurgical Engineers, February 1921, 10 pages). Enunciates a number of rules for the treatment of drills, and in particular emphasises the need for keeping them sharp. A dull drill has to endure far greater stresses to secure rock penetration and hence fails more often.

F. H. Kingdon, *What is the Ideal Drill Steel?* (Paper read before the American Institute of Mining and Metallurgical Engineers, February 1921: Engineering and Mining Journal, April 16, 1921, vol. 111, pp. 668-669). Also bears on the same subject.

F. B. Foley, *Analysis of Some Drill Steel Tests* (Paper read before the American Institute of Mining and Metallurgical Engineers, February 1921, 7 pages). As the result of examining a number of records the conclusion is reached that lack of uniformity in performance in drills shows a lack of uniformity in the heat-treating operations. The remedy is to devise automatic and foolproof heat-treating methods which will attain results without calling for excessive skill on the part of the smith.

P. A. E. Armstrong, *Drill Steel from Hollow Ingots* (Paper read before the American Institute of Mining and Metallurgical Engineers, February 1921: Chemical and Metallurgical Engineering, June 1, 1921, vol. 24, pp. 960-964). The method employed by the Ludlum Steel Co. in the manufacture of hollow drill steel is to insert a high-grade low carbon mild steel tube into an ingot mould, and cast the hot metal around the tube. The tube is filled with sand so as to prevent oxidation and scaling of the inside of the tube. The ingots are then rolled in the usual way down to the finished bar. The bars are cut up into the required length and the sand extracted by special methods. In ingots made by the tube method, segregation is so located as to have very little mechanical effect. The mild steel tube when heated up to the high temperature imparted by the cast metal is enlarged and continues to be enlarged until it reaches a maximum temperature. It then shrinks while the ingot cools, thereby relieving the exterior surface of the ingot from cracking, or having so much strain as a solid ingot.

H. E. Hemstreet, *Design and Heat Treatment of Leaf Springs* (Forging and Heat Treating, April 1921, vol. 7, pp. 240-242). The changes that have taken place in the design, manufacture, and heat treatment of leaf springs are discussed.

E. P. Stenger and B. H. Stenger, *Effect of Heat Treatment on the Fatigue Strength of Steel* (Transactions of the American Society for Steel Treating, August 1921, vol. 1, pp. 617-638). The results are given of an investigation of the fatigue of carbon spring steel and a comparison is made with the results obtained by previous investigators. It is concluded that there is but one certain quenching temperature which yields maximum fatigue strength, which in the case of high carbon steel, corresponds closely to the A_{cm} point. The drawing temperature also has a decided effect on the fatigue strength, and there is one drawing temperature which yields maximum fatigue strength. After this maximum is reached, higher drawing temperatures bring about a rapid lowering of fatigue strength.

E. J. Janitzky, *A Contribution to the Problem of the Influence of Mass in Heat Treatment* (Transactions of the American Society for Steel Treating, October 1921, vol. 2, pp. 55-62). From the results of a number of tests, the records of which are given in tables and graphs, on an 0.45 carbon steel, it is concluded that the factors which control hardness in any carbon steel are the drasticity of the quenching medium and the extent of the tempering operation. As the former becomes less and the degree of tempering greater the vertical asymptote d moves towards the left, into the second quadrant of the system of co-ordinates. The Brinell and tensile curves run parallel and have a hyperbolic tendency.

C. A. Brooks, *Heat Treatment not always the Cause of Failure* (*Ibid.*, vol. 2, pp. 72-73). Too many failures are attributed to faulty heat treatment. Other sources of defects and non-success are discussed.

J. L. Thorne, *Heat Treatment of High-Speed Steel* (*Ibid.*, September 1921, vol. 1, pp. 727-733). Advocates salt baths at 1100° to 1130° F., in lieu of oil baths for quenching and tempering. Care in handling and a reliable pyrometer equipment are required.

P. E. McKinney, *Observations made in the Heat Treatment of Ordnance Forgings* (*Ibid.*, September 1921, vol. 1, pp. 738-745). An enumeration of the factors determining the final result and giving a model data sheet or melter's report showing the complete history of each steel heat made, an ingot record, and a forging record.

H. Scott and H. G. Movius, *Thermal and Physical Changes accompanying the Heating of Hardened Carbon Steels* (*Ibid.*, September 1921, vol. 1, pp. 758-774). Bears on "blue heat" and "temper brittleness," and more particularly the thermal change in hardened steel on heating below A_{c1} . The heat evolution which occurs is designated A_{c1} . Some practical conclusions are drawn; amongst others, that an increase in the rate of heating markedly raises the temperature of A_{c1} for a 0.95 per cent. carbon martensitic steel, and still more so for an austenitic

carbon steel. The end point on tempering martensitic steels is 260°C . for zero rate of Ac_t , and represents the natural boundary between martensite and the troostite of tempering.

H. P. Macdonald, *The Electrical Heat Treatment of Steel* (Transactions of the American Society for Steel Treating, December 1920, vol. 1, pp. 198–207). Describes a method of heat treating by the passage of an electric current of high amperage and low voltage. The heat due to the resistance effects the treatment and can be rapidly applied, the material not being subject to scaling, decarbonisation or crystal growth. A constant section is, however, required in the piece subjected to such heat treatment.

H. C. Loudonbeck, *Necessary Precautions to obtain Uniformity in the Heat Treatment of Steel* (Transactions of the American Society for Steel Treating, April 1921, vol. 1, pp. 398–401). The author gives a number of suggestions of a practical nature to avoid irregularities in heat treatment, and emphasises the need of proper marking and storage of material to be treated.

H. I. Coe, *The Heat Treatment of Medium Carbon Steel* (Journal of the Birmingham Metallurgical Society, vol. 7, Part 15, pp. 583–596). The influence of heat treatment on the mechanical properties is discussed.

A. V. Farr, *Treating Metal to Resist Heat* (Iron Trade Review, June 23, 1921, vol. 68, pp. 1724–1727). The calorising of metals for their protection against the action of heat is described. The material is placed in a rotating retort containing finely divided aluminium and is heated in a reducing atmosphere. The calorised surface of the material treated is too hard to be readily machined and withstands abrasion.

A. N. Conarroe, *The Thermal Treatment of Cast Steel* (Transactions of the American Society for Steel Treating, September 1921, vol. 1, pp. 746–757). An account, with photomicrographs, of the heat treatment of castings which can be thus refined until they possess properties comparable with forgings, although longer and more drastic treatment is required. Defects inherent in cast steel are more pronounced, as mechanical working is absent, and foreign inclusions by their segregating influence on ferrite have more effect. Welded castings should be annealed to remove strains and refine the grain.

M. M. Rock, *Heat Treating Improves Castings* (Iron Trade Review, September 15, 1921, vol. 69, pp. 677–679). The influence of heat treatment on the strength of steel castings is discussed.

C. N. Ring, *Annealing and Heat Treating Miscellaneous Steel Castings* (Transactions of the American Society for Steel Treating, March 1921, vol. 1, pp. 342–346). The correct methods of annealing and heat treating steel castings are outlined.

R. B. Kerr, *Hardening Hammer Die Blocks* (Transactions of the American Society for Steel Treating, March 1921, vol. 1, pp. 309–312). The correct treatment for the hardening of steel dies is discussed.

H. Scott, *Oxidation of Carbon Tool Steel on Heating in Air* (Chemical and Metallurgical Engineering, July 13, 1921, vol. 25, pp. 71-74). The comparative oxidation of armco iron and carbon tool steel on heating in air is given in tables and illustrated by photomicrographs. Up to 850° C. and for a period of five hours decarburisation does not appreciably occur, or at any rate scaling keeps pace with it, and the tool steel itself does not evince decarburisation.

O. Lellep, *Scaling or Oxidation and Reduction of Metals in Fuel Fired Furnaces* (Transactions of the American Society for Steel Treating, March 1921, vol. 1, pp. 346-349). The prevention of oxidation in heat-treating furnaces is discussed.

W. R. Shimer, *Manufacture of Steel from Raw Materials to Finished Product—Remarks on Heat Treatment and Fatigue Failures* (Transactions of the American Society for Steel Treating, May 1921, vol. 1, pp. 423-435). After a brief outline of the operations involved in the production of steel, the author shows the various structural changes in steel during manufacture from ingot to finished forging, and exemplifies the effect of the heating operations necessary for the manufacture of a forging from the ingot.

Screw Stock Heat Treated with Oil (Iron Age, September 15, 1921, vol. 108, pp. 660-661). The application of oil-firing for annealing and heat treating is dealt with, and the operation of the Mirco system is described.

A. A. Blue, *Heat Treatment of Screw Stock* (Forging and Heat Treating, May 1921, vol. 7, pp. 265-267).

F. H. Chapin, *Development of the Bolt and Nut Industry* (Iron Age, June 16, 1921, vol. 107, pp. 1609-1610). The author traces the development of this industry in the United States, where machine-made bolts were first made about eighty years ago.

S. E. Derby, *Cooling Oil for Quenching Tanks* (Iron Trade Review, September 15, 1921, vol. 69, pp. 674-676). The cooling of quenching oil is dealt with, and two types of coolers are described.

J. B. Morey, *Efficiency of Various Quenching Mediums with their Practice and Applications* (Transactions of the American Society for Steel Treating, October 1921, vol. 2, pp. 63-69). A general review of currently used liquids for hardening, with their application in particular instances.

V. E. Hillman (*Ibid.*, December, 1920, vol. 1, pp. 161-170). Gives methods for the approximate estimation of hardening efficiency; hardening uniformity; viscosity and flash point, the main criteria of the suitability of a quenching fluid.

W. G. Lottes (*Ibid.*, pp. 181-190). Deals with the same subject and gives a series of comparative tests, using water and oil.

Welding.—E. E. Thum, *Welding, particularly Hammer Welding* (Chemical and Metallurgical Engineering, September 21, 1921, vol. 25, pp. 553-561). A discussion of all the methods of welding currently

practised, and a summary of the advantages of hammer welding and the wide field it offers for satisfactory workmanship and results.

J. H. G. Williams, *Welding in the Drop Forge Shop* (Forging and Heat Treating, September 1921, vol. 7, pp. 453-458). The repair of drop forgings by welding methods is discussed.

R. S. Johnston, *Investigation of Oxy-Acetylene Welding and Cutting Blowpipes* (Mechanical Engineering, May 1921, vol. 43, pp. 305-310, 359). The results are reported of a series of tests carried out by the Bureau of Standards, Washington, on commercial apparatus for cutting and welding by the oxy-acetylene process. The welding tests were performed on $\frac{1}{2}$ -inch and $\frac{3}{4}$ -inch steel plates, and the cutting tests on $\frac{1}{2}$ -inch, 2-inch, 6-inch, and 10-inch material. There is much difference between the characteristics of different blowpipes, and there is no make of apparatus that is equally efficient and economical for all thick masses of metal. A prime essential of a good welding blowpipe is its so-called gas ratio, which should be unity. None of the blowpipes tested proved capable of maintaining a gas ratio of unity during welding, although the welds were made with the greatest care. A blowpipe designed to be free from flash-back due to any obstruction, under all working conditions, will also be the eminently safe blowpipe, and with ordinary care will produce sound welds. It should be so designed that there will be maintained a one-to-one volume delivery of each gas at identical pressures.

Oxy-Acetylene Cutting Machines (Engineering, August 19, 26, 1921, vol. 112, pp. 274-275, 307-311). An oxy-acetylene cutting machine of a new type is illustrated and described. The apparatus, which is named the radiograph, weighs about 50 lbs., and is designed for cutting straight lengths, or circles and arcs of circles. As an example of its performance is mentioned the cutting of a 16-inch armour plate, from which a slab 2 inches thick was cut off, the rate of working being 4 inches per minute with a consumption of oxygen of $\frac{1}{2}$ cubic foot per square inch of cut, at a pressure of 140 lbs. to the square inch. Other types of cutting machines by the same makers are also described.

F. W. Smith, *Choosing Gas Welding Apparatus* (Iron Trade Review, May 12, 1921, vol. 68, pp. 1314-1316). Some of the problems of welding and cutting are discussed, and the selection of suitable equipment for different operations is dealt with.

A. M. Candy, *Electric Arc Welding* (The Foundry, March 1, 1921). The conditions necessary for securing a good weld and the requirements of a good welding machine are reviewed. Comparative results of tensile tests on welded and unwelded material are given. For five welded test-pieces the breaking load was 23 tons, the yield point 13.25 tons, the elongation varied from 5 to 10 per cent., and the reduction of area from 14 to 22 per cent. In five unwelded test-bars of the same material the breaking load was 27.5 tons, the yield point 17 tons, the elongation varied from 31 to 36 per cent., and the reduction of area from 38 to 58 per cent.

M. Lebrun, *Electric Arc-Welding with Covered Metallic Electrodes* (Revue de Métallurgie, Mémoires, April 1921, vol. 18, pp. 201-212). The improvement introduced by Kjellberg consists in stabilising the direction of the arc by coating the electrode with non-conducting material, and the sheath thus provided opposes the displacement of the arc and confines it to travelling in the direction of the axis of the electrode, enabling the molten metal to be directed where desired. Another form of coating consists of asbestos dipped in various solutions, with a very fine aluminium wire laid along the electrode under the covering to serve as a deoxidiser. A slag is then produced which protects the molten metal from oxidation. Le Chatelier has also proposed a covering of a composition based on silica and metallic oxides, giving slags of a fusibility ranging from 1000° to 1500° C.

O. H. Eschholz, *Properties of Arc-Fused Metal* (Power, February 15, 1921, vol. 63, pp. 250-255). In arc-welding the metal deposited consists of an aggregate of fused globules, about 30,000 globules forming 1 lb. of metal. At the electrode arc terminal these are found to have a temperature of about 2500° C., and they cool at a very rapid rate after deposition. Tests show that the best physical properties result if the metal has been deposited in the direction of stress. In general the properties of arc-deposited metal approximate to those of an ordinary low-carbon boiler plate or unannealed low carbon cast steel.

B. C. Tracey, *Arc Welding for Repair Work* (General Electric Review, June 1921, vol. 24, pp. 587-590). Instances are given of the use of arc welding for the repair of machine parts, such as turbines and worn armature shafts, with notes as to the cost of the repairs.

New Arc Welding Machine (Engineer, July 1, 1921, vol. 132, pp. 18-19). A description of a new machine specially designed for welding studs on to plates, which constitutes a considerable economy over the method of drilling and tapping.

The Hyde Welding Process (Engineering, September 2, 1921, vol. 112, pp. 338-339). This method of welding consists in uniting the surfaces of iron or steel articles by means of molten copper, but it differs from brazing in the fact that the copper impregnates the masses to be joined. The pieces are placed together with a small strip of copper adjacent to but not between the joint, and the whole is then raised to the melting point of copper while surrounded by an atmosphere of hydrogen. No flux is used, and the pieces unite in such a way that they cannot again be separated by heating them.

A. S. Kinsey, *The Possibilities of Fusion Welding* (Paper read before the American Welding Society, May 6, 1921: Iron Age, August 11, 1921, vol. 108, pp. 327-328). The factors depending on a good fusion weld are discussed.

W. T. Ober, *Rock Drill Steels too Short for Use Reclaimed by Welding* (Paper read before the American Institute of Mining and Metallurgical Engineers: reprinted in Electrical World, April 23, 1921, 4 pages).

An account of the successful electrical welding of broken rock drills, and of the precautions necessary in carrying out the process.

Kautny, *The Avoidance of Stresses in Welding Cast Iron or other Brittle Metallic Bodies* (Autogene Metallbearbeitung, July 15, 1921, pp. 201-202). On either side of the joint or crack to be welded a piece parallel to the welding surface is cut out with a saw and a piece of soft steel is fitted and welded in.

L. Treuheit, *Welding of Steel Castings* (Stahl und Eisen, September 29, 1921, vol. 41, pp. 1361-1366). A general review of the known welding processes as applied to welding of steel castings.

Restoration of Worn Machine Parts (Engineering, May 27, 1921, vol. 111, p. 655). A method of repairing worn parts of machines is described, which consists in depositing on the part a coating of nickel which is afterwards ground or machined to the proper size. By this method parts made of special steels that have been heat treated are not affected. The process is known as the "Fescol" process, and is worked by the Fletcher Electro Salvage Company, Ltd., London.

R. J. Fletcher, *Rebuilding Worn Machinery Parts: The Fescol Process* (Paper read before the Sheffield Society of Experimental Engineers: Iron and Coal Trades Review, May 27, 1921, vol. 102, p. 724). In the "Fescol" process the part to be treated is subjected to a preliminary grinding, and is then connected to a copper wire suitable to carry an electric current of 100 to 200 amperes density per square foot at a pressure of from four to ten volts, according to conditions. The part is then submerged in an alkaline electro-cleaning vat, and after removal of all traces of grease, the portion on which the deposit is required is damped and the whole job immersed in a molten wax composition. The portion to be treated is easily stripped of the wax by means of a knife. The part is again immersed in the electro-cleaning vat and on removal only requires rinsing in clean water before being transferred to the depositing vat, where it is left until it has received the required thickness of metal. The metal deposited is usually nickel.

PHYSICAL AND CHEMICAL PROPERTIES.

Properties of Cast Iron.—J. Shaw, *Some Perplexing Foundry Problems* (Paper read before the Institution of British Foundrymen, September 1921 : Foundry Trade Journal, September 29, 1921, vol. 24, pp. 257-264). A general discussion on the properties of cast iron. The presence of oxygen in cast iron and the discrepancies that occur between the physical properties and the chemical composition were discussed.

Cast Iron for Automobile Engine Castings (Foundry Trade Journal, August 25, September 15, October 16, 1921, vol. 24, pp. 151-153, 212-214, 274). The properties and characteristics of grey cast iron for the production of engine-parts are discussed.

J. E. Hurst, *The Influence of Special Elements when added to Commercial Cast Iron* (Foundry Trade Journal, June 9, 16, 1921, vol. 23, pp. 512-514, 530-531). The conclusions arrived at by previous investigators have been summarised.

Testing Appliances.—C. E. Margerum, *Impact Testing Machine for Testing the Impact Strength of Hardened Steel* (Paper read before the American Society for Testing Materials : Engineer, August 6, 1921, vol. 132, p. 150). A new device for testing the shock strength of hardened steel has been designed by the author. The specimen in the form of a beam is supported underneath at the centre, and is acted upon towards its ends by a forked plunger resting on it to which blows are delivered by a hammer moving at any velocity up to 32 feet per second. The centre piece which supports the specimen rests on a 10-millimetre steel ball, which in turn is supported on the surface of a record bar. The maximum load sustained by the specimen is determined from the size of the impression made by the ball on the record bar. In the machine used by the author the record bars were cut from a nickel-chrome forging hardened and drawn to a Brinell figure of 270. The breaking strength of the specimen is expressed in pounds per square inch, and is actually the maximum pressure at the centre of the bar. The velocity of the hammer seems to affect the recorded impact strength, the higher the velocity the greater being the recorded strength.

C. E. Margerum, *Test for Shock Strength of Hardened Steel* (Forging and Heat Treating, September 1921, vol. 7, pp. 488-490). The apparatus and methods for determining the strength of hardened steel under impact loading are described.

E. Irion, *Hardness Testing Machines* (Zeitschrift des Vereines Deutscher Ingenieure, March 26, 1921, vol. 65, pp. 315-320). Illustrated descriptions of various hardness testing machines of the Brinell type are given, as constructed by the Düsseldorfer Maschinenbau A. G. These include machines for pressures of 750 to 1500 kilogrammes and more powerful ones for loads up to 10,000 kilogrammes. For testing rails a machine for loads up to 50 tons has been devised. The Martens-Heyn modification of the Brinell test consists in measuring the load required to press a 5-millimetre ball to a depth of 0.05 millimetres into the specimen. For the hardest materials loads of 250 to 500 kilogrammes are found to be sufficient. Diagrams show the variation in the coefficient, giving the relation between the Brinell number and the tensile strength. With constant load the hardness number is lower the larger the ball diameter, and with constant ball diameter the hardness number varies with the load. Results of tests on various materials are given, using balls of 5 and 10 millimetres diameter, and loads from 2000 to 3000 kilogrammes. It is found that in order to obtain comparable results from the Brinell and Martens-Heyn tests a ball of 6.35 millimetres diameter must be used.

Brinell Testing Machine for Large Forgings (Engineering, June 3, 1921, vol. 111, p. 680). A descriptive note with illustrations is given of the machine.

Hardness Testing of Metals (Report of a Committee of the Engineering Division of the National Research Council: Mechanical Engineering, July 1921, vol. 43, pp. 445-449). By the use of an etched ball for the Brinell hardness test, indentations are obtained which are easier to read than those produced with polished balls, due to the contrast between the dull indentation surface produced by the etched ball and the surrounding surface. The method was devised by A. Hultgren, and illustrations show the advantage of its application. The balls used for the experiments were etched in a 1 per cent. alcoholic solution of nitric acid for two minutes. The Morin hardness testing apparatus is next described, and also the Brinell meter, which is operated on a similar principle.

T. Y. Olsen, *Recent Developments in Testing Machines* (Forging and Heat Treating, February-March 1921, vol. 7, pp. 131-134, 162-165). The article describes testing machines of various types, including impact tension, impact shear, repeated impact, toughness and endurance, alternate torsion and transverse testing machines.

P. Beuret, *Measurement of Wear* (Revue de Métallurgie, Mémoires, March 1921, vol. 18, pp. 157-160). An appliance of simple design is described, which has been devised for measuring the wear of surfaces of irregular profile, such as the teeth of gear wheels.

Tests and Properties of Materials.—H. J. Gough, *Improved Method for Fatigue Testing* (Engineer, August 12, 1921, vol. 132, pp. 159-162). The results of tests by the method of Smith and Stromeier are dis-

cussed, with notes on the measurement of the heat developed and the deformation of test-pieces at varying speeds and loads of the machine.

H. F. Moore, *Investigation of Fatigue of Metals under Stress* (Paper read before the American Institute of Mining and Metallurgical Engineers, February 1921, 2 pages). Extremes are to be found in the facts that while a homogeneous steel like Armco, thoroughly annealed, will endure over a hundred million reversals of stresses as high as its elastic limit without any signs of failure, a complex structured steel like chromium-nickel steel will fail at a stress of 58 per cent. of its elastic limit. The author has never encountered any failure that cannot be explained by localised high stress at a nick, a crack, or some other local defect such as local blue brittleness, or a discontinuity of heat treatment.

J. Miller, *Fatigue Breakdown in Automobile Steels* (Transactions of the American Society for Steel Treating, March 1921, vol. 1, pp. 321-325). A number of experiments carried out on a Stanton fatigue testing machine indicate that a 3.5 per cent. nickel steel with 0.20 per cent. carbon, carbonised 0.04 to 0.06 inch and quenched in oil from a temperature high enough to break up the cementite, gives results difficult to surpass with any other steel or treatment, regarding fatigue-resisting properties.

P. Kreuzpointner, *The Fatigue of Metals* (Engineering and Mining Journal, August 6, 1921, vol. 112, pp. 216-217). The phenomena of fatigue and the effect of rest on fatigued steel is briefly discussed.

J. E. Howard, *Relations between the Physical Properties of Steels and their Endurance in Service* (Transactions of the American Society for Steel Treating, August 1921, vol. 1, pp. 673-682).

F. Eloy, *Influence of Repeated Compression Shocks on Steel* (Revue de l'Industrie Minérale, October 1, 1921, pp. 603-606). In machine parts, such as shoes and stamps in crushing machinery, the requirement is metal that will withstand repeated compressive stresses. In such circumstances steel, particularly carbon steel, which will well resist other stresses, may fail. A high elastic limit and impact resistance are required, and alloy steels behave better than plain carbon steels.

J. H. G. Monypenny, *Elongation and Gauge Length in Tensile Tests* (Engineer, August 26, 1921, vol. 132, pp. 220-221). The total elongation obtained from any test-piece is made up of two distinct parts: (a) The approximately uniform elongation over the whole length of the piece, and (b) the local elongation due to the neck, this part being independent of the length of the test-piece. The constants, relating length to area, vary greatly in the standard forms adopted in different countries, and a series of comparative tests has been carried out in the endeavour to fix some approximate relationship for commercial use between the values given by British, French, and German standard test-pieces. The constants by which the elongation on the

British test-piece should be multiplied to obtain the equivalent values of the foreign test-piece are given below :

	Elongation per Cent. on	
	French Test-Piece.	German Test-Piece.
Normalised or rolled steel . .	0.77	0.69
Hardened or tempered steels . .	0.69	0.59

These values are only approximate, but the differences are not great.

T. Hudson and W. Gordon, *Influence of Width of Specimen on the Results of Tensile Steel Tests of Mild Steel and Copper* (Paper read before Section G of the British Association, September 1921). Experiments were carried out on $\frac{1}{4}$ -inch mild steel plates (carbon between 0.12 and 0.15 per cent.), $\frac{1}{8}$ -inch mild steel plate (carbon 0.13 per cent.), and $\frac{1}{8}$ -inch copper plate. The results showed that the yield point remained practically constant over the entire range of observation in each case, the average value being 18.14 tons per square inch for the $\frac{1}{4}$ -inch plate, 12.82 tons for the $\frac{1}{8}$ -inch steel plate, and 7.32 tons for the copper plate. The tenacity or commercial maximum tensile stress appears to be but little affected. In the case of the two steels there was a slight tendency to rise as the width increased, but this effect was noticeably absent in the case of copper. The average values were 25.48 tons per square inch for the thicker steel, 22.37 tons for the thinner steel, and 14.52 tons per square inch for the copper.

H. O'Neill, *Calculation of Mechanical Properties of Steel from its Chemical Composition* (Iron and Coal Trades Review, May 20, 1921, vol. 102, p. 700). A discussion of the work of past investigators.

E. G. Coker, *Effects of Scratches in Materials* (Paper read before the Engineering Conference of the Institution of Civil Engineers, 1921). The increased strength and extension due to a high degree of polish in a tension test-piece has been frequently noted, and the elimination of scratches appears to be of importance. The form of scratch produced is all important, and a comparative estimate of various types can be easily obtained without microscopic examination by examining notches on a large scale under conditions in which the influence of boundaries, other than those of the notches themselves, are practically unimportant. If this is done it can be shown, for example, that a scratch producing a semi-circular groove in the material may raise the stress to about double the average stress, while a groove with straight sides at 45 degrees and a radius at the apex of one-eighth of the depth gives an increase of rather less than five times the mean stress.

R. S. MacPherran, *Comparative Tests of Steels at High Temperature* (Paper read before the American Society for Testing Materials, June 24, 1921). The result of tensile tests shows that the maximum tensile strength for rolled carbon steel annealed occurs at 315° to 345° C. The maximum tensile strength occurs at a higher temperature than the minimum ductility. The presence of nickel above 3.25 per cent.

lowers the temperature of maximum strength. Chromium steels appear to be less affected by a rise in temperature than carbon steels.

E. L. Dupuy, *An Experimental Investigation of the Mechanical Properties of Steels at High Temperatures* (Revue de Métallurgie, Mémoires, June 1921, vol. 18, pp. 331-365). A French translation of the paper read before the Iron and Steel Institute in Paris, in September, and published in the current Journal.

H. Edert, *Minute Measurements in making Hot Tensile Tests* (Stahl und Eisen, April 14, 1921, vol. 41, pp. 510-511). An apparatus for carrying very small measurements in testing hot material is illustrated and described.

P. Junkers, *Forging Tests on Mild Steel* (Stahl und Eisen, May 19, 1921, vol. 41, pp. 677-687).

The Hardness Testing of Metals (Forging and Heat Treating, September 1921, vol. 7, pp. 480-486). The report of a Committee of the Engineering Division of the National Research Council on various methods of testing the hardness of metal is given at length.

F. Waizenegger, *Note on Hardness Testing* (Zeitschrift des Vereines Deutscher Ingenieure, July 30, 1921, vol. 65, pp. 824-827).

C. Fremont, *Stamping Tests of Thin Steel Sheets* (Bulletin de la Société d'Encouragement, March 1921, vol. 120, pp. 241-253). Experiments were made to determine the relation between the behaviour of steel sheets in the stamping press and their mechanical properties.

A. Portevin and P. Chevenard, *Remarks and Observations relating to the Phenomena of Hardening in Steels* (Revue de Métallurgie, Mémoires, July 1921, vol. 18, p. 428). Discusses, in the first instance, the methods and appliances employed in plotting differential dilatometric curves, and the precautions to be observed in their interpretation. The problem of retarded solution and of the premature precipitation of cementite is then dealt with. Any given hardened steel almost invariably contains: (1) metal transformed at high temperature (ferrite or troostite); (2) metal transformed at low temperature; and (3) untransformed metal (austenite). The practical bearing of this structure is considered, after which the constituents of the iron-iron carbide system are discussed from the point of view of their relative states of equilibrium, preference being made to the Bancroft-Ostwald law that in eutectic steels the resulting state is not the most stable but the state most closely approximating thereto. The non-nickel system is then dealt with and a parallel drawn, and illustrated by means of tables, between what occurs in iron-nickel alloys, and in ordinary carbon-steel.

B. Strauss, *The Hardening of Steel* (Krupp'sche Monatshefte, May 1921, pp. 81-89). The author deals with Maurer's theory of hardening, and the dependence of hardening upon composition, temperature, and rate of cooling. The cause of quenching cracks is explained with practical observations on hardening generally.

P. Dejean, *On the Nature of the Transformations which Occur during*

the Hardening of Steels (Revue de Métallurgie, Mémoires, July 1921, vol. 18, pp. 419–427). Reviews current theories and opinions and suggests a new nomenclature for some of the critical points. Defines Ar3 as the commencement of the transformation of γ -iron to α -iron, and the separation of α -iron from austenite, and Ar1 as the eutectoid point below which, under normal conditions, iron carbide (cementite) cannot remain in solution in iron.

O. Bauer and W. Schneider, *Hardening of Electrolytic Iron by Quenching* (Stahl und Eisen, May 12, 1921, vol. 41, pp. 647–648). Experiments were made for the purpose of confirming or otherwise the results obtained by H. C. Boynton from his investigation of the hardness of the constituents of iron and steel (*Journal of the Iron and Steel Institute*, 1906, No. II. p. 287). Boynton found on quenching electrolytic iron from 950° C., the average hardness number, as recorded by Jagger's microsclerometer (abrasion method), was raised from 505° to 998°. The present authors prepared test-pieces of electrolytic iron annealed at 950° C. and quenched them from different temperatures varying from 650° to 1200°. Neither the Brinell hardness nor the ultimate breaking load showed any marked variation. The fact that the principle of the method of hardness measurement employed by Boynton was totally different from the Brinell method is thought to account for the great difference in the results of the experiments described.

E. Heyn, *Recent Researches on the Notch Effect, in Particular by Optical Methods* (Stahl und Eisen, April 21, May 5, 1921, vol. 41, pp. 541–546, 611–617). The author describes experiments based on the investigations of Kirsch, Inglis, and Coker, to determine the effect of holes and notches on the distribution of stress in material.

T. G. Tulloch, *Wear in Big Guns* (Pamphlet published by the Royal United Services Institution, Woolwich, 1921). The influence of erosion and corrosion on the wear of guns is discussed.

J. Hanny, *Fibrous Fracture in Steel* (Stahl und Eisen, September 15, 1921, vol. 41, pp. 1298–1300). Fibrous fracture in steel for guns has been traced to the pressure of small carbon monoxide blowholes which originate from oxides contained in the steel. By a suitable method of working the open-hearth, and of teeming in the ladles and moulds, it was found possible to obviate fibrous fracture, but further experiment in the determination of oxygen and occluded gases is necessary before it can be definitely proved that such blowholes are the true cause of fibrous fracture.

E. M. Horsburgh, *The Fracture of Wire in Steel Ropes* (Paper read before the British Association, September 1921: Colliery Guardian, September 23, 1921, vol. 122, p. 870). The mathematical principles involved in examining the strength of steel ropes and the fracture of wire ropes are discussed.

R. H. Greaves, *Effect of Overstrain on the Elastic Properties of Steel* (Research Department, Woolwich, Report No. 45: Iron and Coal Trades Review, July 15, 1921, vol. 103, p. 73). The results are given

of a series of experiments conducted on six different steels. The author concludes that while the results reported do not fully cover the ground, they throw light on the phenomena of overstrain, and subsequent recovery of elasticity, by indicating some important effects of variation in composition of the steel and in degree of overstrain. After overstrain in tension recovery proceeds slowly at atmospheric temperature and more rapidly as the temperature is raised, though when the temperature is raised beyond a certain point (differing in different steels) the elastic limit begins to fall owing to the usual softening effect. Recovery is not complete in a hard alloy steel after one hour at a temperature as high as 350°C ., but in steels of more ordinary properties recovery occurs rapidly at temperatures not exceeding 200°C .

P. Drosne, *General Considerations relating to Elasticity and Tenacity in Solid Bodies* (Revue de Métallurgie, Mémoires, January 1921, vol. 18, pp. 58-63). Points out that elasticity and tenacity are not in themselves natural "properties" of metals, but the resultant of a number of such properties (such, for instance, as cohesion) and of the external influences brought, at given time, to bear on the metal. They are not, therefore, capable of intrinsic definitions, not being absolute constants. A homogeneous metal assumes, under the action of exterior forces, a system of deformations which is such that the internal work of the cohesive forces *plus* the exterior forces cause a minimum deformation, as compared with all the possible systems of deformation which could be conceived as occurring.

K. Honda and H. Hasimoto, *Changes in the Elasticity and Torsion Modulus in Carbon Steels due to Quenching* (Tohoku University, Science Reports, 1921, vol. 10, pp. 75-77). The modulus of elasticity and that of torsion diminish as the carbon content increases. Both have lower values in hardened steels, and the same is the case with tungsten and chromium steels. The falling-off in the value of the modulus is explained by Honda's theory of hardening.

W. E. Dalby, *The Limit of Elasticity* (Engineering, July 8, 1921, p. 81). The accurate determination of the elastic limit is a matter of difficulty, especially in the case of nickel steel.

J. E. Howard, *Internal Service Strains in Steel* (Chemical and Metallurgical Engineering, August 17, 1921, vol. 25, pp. 275-278). No evidence appears yet to have been adduced to show that any stress, however small, will cause permanent set, and that perfect elasticity or perfect resilience after application of tension is not a fundamental property in steels. Popular impressions are due to insufficient consideration, and the wide range of conditions which affect endurance have been overlooked.

Properties and Uses of Alloy Steels.—*Uses of Stainless Steel* (Engineer, June 3, 1921, vol. 132, p. 599). A summary of the purposes for which stainless steel is successfully used is given, with some instances of difficulties that have been found in treating it and in its adaptability.

The impression that stainless steel cutlery retains its edge badly is due to the fact that it has often not been realised that it requires to be hardened from a temperature 150°C . higher than the usual one for ordinary carbon steel.

W. H. Hatfield (Engineer, June 24, 1921, pp. 663-664). In a letter discussing the above article the necessity of a proper hardening is pointed out, and it is stated that given the correct treatment stainless cutlery will stand ordinary service conditions better than carbon steel. A table is given of the values obtained by oil hardening the steel and tempering at gradually increasing temperatures.

Future of Stainless Steel (Engineer, October 28, 1921, vol. 132, pp. 447-450). A short account is given of the discovery of stainless steel by H. Brearley. Its applications now include, besides the well-known cutlery, the manufacture of turbine blades, pump rams, and other portions of machinery exposed to the action of corrosion.

E. Haynes, *Stainless Steel* (Paper read before the American Iron and Steel Institute, May 27, 1921). The properties and uses of stainless steel are dealt with.

J. L. Cox, *Stainless Steels require most Careful Hardening* (Iron Trade Review, June 23, 1921, p. 1730).

L. Aitchison, *Chromium Steels and Irons* (Paper read before the Institution of Automobile Engineers, November 10, 1921). The author draws attention to the special properties of chromium steels which render them highly suitable for parts of automobiles and aircraft. For ordinary purposes the proportion of chromium in the alloy need not exceed 3 per cent. in order to obtain the requisite mechanical properties. For quite small parts the proportion need not be so high, 1 to 1.5 per cent. chromium being sufficient. In medium carbon steels the influence of a proportion of chromium upon the mechanical properties is at first great, rising rapidly to a maximum which remains constant for increasing percentages of chromium, after which there is a slight falling away. The influence of the proportion of carbon in the steel overshadows the influence of chromium both in the low and high chromium steels. For purposes in which "stainless" properties are valuable, the mechanical requirements are likely to be met fully by the "stainless" irons which are quite as rust-resisting as the high carbon "stainless" steels and very much easier to work. The mechanical advantages of the addition of vanadium to chromium steels are not apparent.

J. A. Mathews, *Molybdenum Steels* (Paper read before the American Institute of Mining and Metallurgical Engineers, February 1921, 5 pages). Molybdenum steel is described as relatively free from defects and to have a wide, safe heat-treatment range. In conjunction with chromium, molybdenum also appears to confer the property of deep hardening. Its increasing use in aeroplane, automobile, and general engineering is prophesied.

A. H. Hunter, *Molybdenum and its Uses in Steel* (Paper read before the American Iron and Steel Institute, May 27, 1921: Iron Trade

Review, June 2, 1921, vol. 68, pp. 1523-1525). The properties and uses of molybdenum, and the manufacture and properties of molybdenum steel are dealt with.

C. McKnight, *A Discussion of Molybdenum Steels* (Transactions of the American Society for Steel Treating, March 1921, vol. 1, pp. 288-296). The uses and properties of molybdenum steels are discussed. The effect of molybdenum in steel is most marked. The tensile properties are raised and the elastic ratio is higher. The most important effect is that of raising the reduction of area with a corresponding increase in the toughness. Molybdenum steels have an extremely wide range for practical heat treatment, a difference in quenching temperature of 100° making little difference in the properties of the finished steel.

M. H. Schmid, *Molybdenum Steel and its Applications* (Transactions of the American Society for Steel Treating, June 1921, vol. 1, pp. 500-505). The manufacture, properties, and uses of molybdenum steel are briefly discussed.

G. W. Sargent, *The Value of Molybdenum Alloy Steels* (Transactions of the American Society for Steel Treating, July 1921, vol. 1, pp. 589-597). The physical characteristics of molybdenum alloy steels are briefly discussed.

W. Guertler, *The Use of Molybdenum as an Alloy Metal* (Zeitschrift für Metallkunde, May 1921, vol. 13, pp. 243-244). Some notes are given on the chemical and physical properties of molybdenum, and its influence on steel and steel alloys, when added to them. The principal purposes for which steel alloys containing molybdenum in varying percentages are used are acid-resisting alloys, magnet steel, high-speed steel, and structural steel. Bridge construction is thought to offer a wide field for the application of molybdenum steel.

Molybdenum Steel in Bridge Building (Zeitschrift des Vereines Deutscher Ingenieure, March 26, 1921, vol. 65, p. 325). In place of nickel steel a molybdenum steel of the following composition is recommended for the structural work of bridges with wide spans: carbon 0.25, manganese 0.75, chromium 0.75, molybdenum 0.75 per cent.

Some Properties of Molybdenum Steels (Engineering, September 2, 1921, vol. 112, pp. 350-351). Results of mechanical tests on steels containing 0.42 to 0.50 per cent. of molybdenum are given.

A. H. d'Arcambal, *Physical Tests on High-Speed Steel* (Paper read before the American Society for Steel Treating, September 20, 1921). The author describes transverse tests at room temperatures and tensile tests ranging from room temperatures to 1200°, conducted on two types of high-speed steels. The results of the tests are given.

R. Vogel, *Tungsten-Nickel Alloys* (Zeitschrift für anorganische Chemie, May 24, 1921, pp. 231-242). A nickel-tungsten diagram is plotted for alloys containing 0 to 80 per cent. tungsten. The compound Ni_6W has a melting point at 1525° and transformation point at 925°. The eutectic point is at 1570° with 52 per cent. tungsten.

W. H. Hatfield, *Further Notes on Automobile Steels* (Paper read

before the Institution of Automobile Engineers, 1921). The author describes some experimental work designed to establish the actual fatigue range of different steels. A Wöhler rotary bend test machine was employed. The test-piece rotates at 1500 revolutions per minute, and the procedure consisted in gradually modifying the load on the bar until that load was attained which the bar would carry without rupture for ten million revolutions. The results obtained from wrought iron, brass, and duralumin are also given. The steels used were carbon steels, case-hardening steels, and alloy steels.

The outstanding fact which is derived so far is that high-tensile alloy steels (maximum stress in tons per square inch, 50–65) have a materially higher fatigue range than carbon steels of the same hardness. For ten million revolutions the safe range of stress for carbon steels, as used in the motor industry, is from 12 to 18 tons per square inch. For alloy steels the comparative figures are 21·5 to 28 tons. The report concludes with a complete bibliography of the literature on alternating stress tests.

C. M. Johnson, *Some Alloy Steels of High Elastic Limit, their Micro-structure and Heat Treatment* (Paper read before the American Society for Steel Treating, September 22, 1921). The results of heat treatment and physical tests on a series of nickel-silicon steels, containing small percentages of chromium, vanadium, and other elements, are given.

A. E. White, *Alloy Steel* (Transactions of the American Society for Steel Treating, June 1921, vol. 1, pp. 481–499). The constitution of alloy steels is discussed.

H. C. Knerr, *Three Types of Alloy Sheet Steel* (Iron Age, September 8, 15, 1921, vol. 108, pp. 594–596, 655–658). A report of an investigation of three commercial types of alloy steel in sheet form, to determine their suitability for use in the manufacture of fittings for large aircraft. The sheets were rolled from samples of nickel steel, nickel-chromium steel, and chromium-vanadium steel. The results are given of the heat treatment and tests. The nickel steel and nickel-chromium steel failed under the bend test and were found not suitable for the manufacture of fittings of the type intended, whereas the chromium-vanadium steel showed excellent qualities in bending, and was also satisfactory under all the other tests applied.

E. W. Rettew and L. A. Lanning, *Effect of Phosphorus and Sulphur on Steel* (Transactions of the American Society for Steel Treating, January 1921, vol. 1, pp. 247–249). The effect of these elements on the properties of steel is briefly discussed.

L. Guillet, *The Theory of Metallic Alloys and its Chief Industrial Applications* (Chimie et Industrie, May 1921, vol. 5, pp. 500–507). The concluding portions of a detailed study of alloys and of their practical employment.

Wear, Failure, and Defects of Material.—J. E. Howard, *Split-Head Rail Failure Shows Rupture* (Iron Age, August 18, 1921, vol. 108, pp. 393–394). A microscopic examination has been made of a Bessemer

steel rail which failed owing to a split-head fracture, causing the derailment of a train. This type of fracture is the result of distortion by wheel loads of the grain of the steel and induces lateral flow of the metal at the running surface of the rail, the tendency of such loads being to spread the rail heads.

J. E. Howard, *Punishment of Rails* (Iron Age, May 26, 1921, vol. 107, pp. 1375-1376). Attention is drawn to the difference, both in origin and effect, of rail hardness produced by the cold rolling action of wheels and by their slipping.

P. Oberhoffer, *Cause of Corrugation in Tram Rails* (Stahl und Eisen, August 18, 1921, vol. 41, pp. 1137-1141). A review of several recent investigations into the cause of corrugation. The microscopic study of corrugated rails is recommended as the best means for the further elucidation of the phenomenon.

A. Wichert, *Rail Corrugation due to Frictional Vibrations* (Stahl und Eisen, August 25, 1921, vol. 41, pp. 1181-1187). The author puts forward a new theory to explain the cause of rail corrugation. Frictional vibration occurs when a body capable of vibrating slides upon another consequent upon the decrease of the coefficient of friction as the speed of friction decreases. The frictional vibration set up on starting, braking on curves, and by lateral movements of the wheels on the rails causes an intermittent pressure on the rail surface, which soon leads to corrugation of the surface locally affected. Given the use of wheels and axles of ample solidity, corrugation would not occur within certain speed limits.

A. Mesnager, *Tests with Special Steels for Railways and Tramways* (Genie Civil, August 13, 1921, vol. 79, p. 155). The Hadfield steel, containing 12 per cent. manganese and 1.4 per cent. carbon, is very suitable for railway parts exposed to heavy wear and tear and great stresses, but the cost is exceedingly high. Titanium steel rails show a greater degree of hardness. Rails made according to the Sandberg process, with high silicon or with sorbitic structure, are said to have little advantage over rails of ordinary steel, and manifest a tendency to corrugation.

C. P. Sandberg, *Damage to Tyres and Rails caused by Brakes or Slipping Wheels* (Paper read before the Engineering Conference of the Institution of Civil Engineers: Iron and Coal Trades Review, July 1, 1921, vol. 103, p. 9). Both direct experiments and the examination of specimens from materials which have been subjected to service conditions indicate that in addition to the thermal formation of a hardened skin the following action may also take place: Sliding of one surface over the other proceeds to a point at which both surfaces have become so heated that they are soft and plastic and tend to seize together at numerous points of contact. Whilst so united the surface layers are dragged bodily forward, forming an overlap in advance of each area of adhesion and a tear behind it. The adhesion is only momentary, and the surfaces are quickly dragged apart, and recom-

mence to slip over one another until sufficient rise of temperature and softening have occurred to cause another seizing. This alternating action of seize and slip probably occurs many times per second during the application of the brakes. The result is to produce a series of surface tears or cracks upon both brake block and the wheel or rail, the cracks running in a direction at right angles to that of the motion and forming at regularly spaced intervals, evidently bearing a relation to the periods of slip and seize.

M. Klein, *The Boiler Explosion at Electric Works at Abo* (Zeitschrift des Vereines deutscher Ingenieure, August 13, 1921, vol. 65, pp. 869-870). A serious boiler explosion occurred at the electric central supply station at Abo, in Finland. Impact tests on specimens taken from the boiler plates showed that the plates as delivered were brittle, indicating an unsuitable or incorrect heat treatment. The grain was fairly coarse.

Specifications.—*A New Rail Specification Proposed* (Iron Age, August 4, 1921, vol. 108, pp. 262-263). A new specification is proposed by R. W. Hunt, which provides for the rolling of tie-plates from ingot tops, and restriction of cold straightening. The chemical and physical requirements of the specification are given.

Australian Standard Specifications for Railway Rails and Fishplates (Australia, Institute of Science and Industry, 1921. Publication No. 3).

French Specifications for Carbon Steels (Iron Age, May 26, 1921, vol. 107, pp. 1373-1374). A translation is given of the French Specification No. A2-1-U.F., prepared by the French Permanent Commission on Standardisation.

French Standard Sections (Bulletin Technique du Bureau Veritas, February 1921, vol. 3, pp. 39-42). A list of standard sections adopted by the French Standardisation Committee. The list includes all profiles of general use and those used in shipbuilding and mines.

H. J. Force, *Some Failures of Chilled Cast Iron Wheels* (Paper read before the American Society for Testing Materials, June 24, 1921: Iron Age, June 30, 1921, vol. 107, pp. 1760-1761). The author points out the need for the purchase of car wheels to a chemical specification. Tables are given showing the composition of a number of wheels which have failed or worn out in service. The wheel with the lowest sulphur and lowest phosphorus apparently gave the best service. The higher silicon wheels in all cases showed more wear than lower silicon wheels. The following specification is recommended, covering all weights of chilled iron wheels:

	Per Cent.
Total carbon	3 -3.65
Combined carbon	0.45-0.85
Manganese	0.50-0.75
Phosphorus	Not over 0.32
Sulphur	Not over 0.17
Silicon	0.45-0.75

It is also recommended that consideration be given to a wheel which contains a small percentage of nickel and chromium. Wherever wheels of this composition have been used the results have been highly satisfactory.

	Per Cent.
Total carbon	3.20-3.75
Combined carbon	0.40-0.80
Manganese	0.45-0.65
Phosphorus	Not over 0.15
Sulphur	Not over 0.17
Silicon	0.45-0.70
Chromium	0.10-0.25
Nickel	0.10-0.20

H. C. Knerr and A. L. Collins, *Universal Steel Classification Code* (Iron Age, September 1, 1921, vol. 108, pp. 515-517). The authors propose a system of classifying steels to supplant the system inaugurated by the Society of Automobile Engineers in 1912. In the proposed system the elements are symbolised by a single and distinctive letter which suggests, in some degree, its name or chemical symbol. In order to indicate, approximately, the quantity of any alloying element, numbers are used.

Ageing of Steel.—H. J. French, *Artificial Seasoning of Steels* (Chemical and Metallurgical Engineering, July 27, 1921, vol. 25, pp. 155-158). Early work on the seasoning or ageing of steel, and evidence that steel properties actually do change with efflux of time, are reviewed, and the fact that dimensional changes of this nature are known to occur in hardened reference gauges is noted, with instances. Experiments were carried out with a number of United States Ordnance Department gauges in 1919, the methods and results being given. Some of the results varied even in the same gauges. Plain carbon steel with 1.18 per cent. of carbon appears the least desirable as regards permanence, showing the greatest changes in length and planeness. In some of the specimens shrinkage occurred.

Magnetic Properties of Iron and Alloys.—K. Onnes, Sir R. A. Hadfield, and H. R. Woltjer, *On the Influence of Low Temperatures on the Magnetic Properties of Alloys of Iron with Nickel and Manganese* (Proceedings of the Royal Society, June 1921, Series A, vol. 99, pp. 174-196). A series of such alloys with varying percentages of nickel and manganese respectively were tested at liquid hydrogen and liquid helium temperatures, the apparatus employed being described. The iron-manganese alloys with the higher manganese percentages cannot be made magnetic by such means, but evidence was obtained of the probable existence of one magnetic, and one non-magnetic or slightly magnetic manganese-iron compound, and an explanation found of the non-magnetic properties of the higher manganese-iron alloys.

E. Gumlich, *The Magnetic Properties of Electrolytic Iron* (Stahl

und Eisen, September 8, 1921, vol. 41, pp. 1249-1254). Electrolytic iron, when annealed, and especially after melting *in vacuo*, furnishes a most excellent material for electro-technical purposes, especially for cores of magnets, or yokes of electro-magnets, and parts of machines which require to have a high degree of permeability.

E. L. Dupuy, *The Influence of Welding on the Resistivity of Iron* (Comptes Rendus, June 27, 1921). The presence of ferric oxide in the metal causes an increase in the electrical resistance.

E. L. Dupuy, *Influence of Rolling on the Electrical Resistance of Steel* (Comptes Rendus, 1921, vol. 172, pp. 1660-1662). If a bar of steel be drawn into wire the electrical resistance decreases as the section decreases. If annealed at 800° and the original structure is restored, the variation though lessened still persists.

C. Shenfer, *Partial Demagnetisation* (Electrician, August 26, 1921, vol. 87, pp. 263-266). The influence of partial demagnetisation on the permanency of magnets is discussed, and a method of artificial maturing, in which the magnet is magnetised up to saturation, and then subjected to mechanical shocks, is described.

Magnetic Analysis.—C. W. Burrows, *Application of Magnetic Analysis to Rock Drills* (Paper read before the American Institute of Mining and Metallurgical Engineers, February 1921, 10 pages). After giving a brief account of the stresses occurring in rock drills and the resulting failure on fatigue, the application of magnetic tests by means of the defectoscope, for ascertaining the portions of the bar in which weakness, and the resulting fatigue, occur. Recovery from the effects of fatigue will result from cessation of alternating stresses for any time and at any temperature. Experimental investigation of the conditions under which restoration takes place is advocated.

Radiography of Metals.—S. Nishikawa and G. Asahara, *Investigation of Metals with Röntgen Rays* (Physical Review, 1920, vol. 15; Zeitschrift für Metallkunde, June 1921, vol. 13, pp. 282-286). Radiographs are shown of a number of metals which have been subjected to mechanical operations and various heat treatments.

E. C. Bain, *Studies of Crystal Structure with X-Rays* (Chemical and Metallurgical Engineering, October 5, 1921, vol. 25, pp. 657-664). The practical details of X-ray examination of metals are described and illustrated, a method being given for the analysis of atomic spacing by the Coolidge tube, and a diagram of the wiring and general arrangements shown. For filtration 0.35 thicknesses of zirconia are used. A fine-grained metal gives a good distribution of smooth lines on the film, while a coarse-grained structure is spotted, and shows dashed lines. In some cases, patterns are indistinguishable from each other, as in the case of austenitic manganese steel and nickel, but generally speaking the pattern is absolutely characteristic of one substance. As a method of quantitative estimation, radio-

graphy holds little prospect of success. The fact that some lattices are not changed by an addition or a change in the constituent percentages seems to show that in metals with limited solubility atoms of the solute simply replace atoms of the solvent with more or less uniformity of distribution. Eutectic mixtures usually show coarser grain characteristics for the pattern of one of the constituents than for the other. The most striking use of the method is the detection of allotropy. There are marked differences between the α - and γ -iron patterns. The method may be expected to supply answers to many questions as yet unsettled.

Metallography, Crystallography, and Constitution of Steels.—

A. Fry, *Stress Effect Lines in Mild Steel, as Revealed by a New Etching Process* (Stahl und Eisen, August 11, 1921, vol. 41, pp. 1093–1097). In subjecting steel bars to stresses producing slight deformation, certain lines appear on the surface of the stressed material, which the author calls stress effect lines or figures. With ordinary etching media it has not hitherto been possible to develop the structure of the piece, where the markings occur, in such a way as to reveal the difference between the figured and plain parts of the area affected. An etching medium has now been found which brings out the stress effect lines, where the copper ammonium chloride completely fails to do so. For microscopic etching the composition of the new medium is :

Hydrochloric acid, concentrated	.	.	40 c.c.
Water	.	.	30 "
Ethyl alcohol	.	.	25 "
Crystalline copper chloride	.	.	5 grammes

The specimen is first polished in the usual way. For macroscopic work the etching fluid has the following composition :

Hydrochloric acid, concentrated	.	.	120 c.c.
Water	.	.	100 "
Crystalline copper chloride	.	.	90 grammes

The quantity of free acid is so proportioned that free copper cannot be deposited on the iron. The specimen is placed in the solution for two or three minutes, then taken out and the surface is rubbed with powdered copper chloride applied with a rag that has first been thoroughly steeped in the solution. Dark bands appear where a disturbance of the crystals has taken place, and it is possible to distinguish under the microscope whether the disturbances producing the stress effect lines are due to disintegration of crystals, deformation of crystal boundaries, or slipping of crystal surfaces.

B. Strauss and A. Fry, *Formation of Cracks in Boiler-Plates* (Stahl und Eisen, August 18, 1921, vol. 41, pp. 1133–1137). Fry's new etching reagent has been used in an investigation of old and new

boiler-plates. The stress effect lines or bands are plainly visible in the old plates in the neighbourhood of cracks and rivet-holes. Certain of the new plates as delivered showed the bands clearly, after heating to 200° C. It was immediately discovered that these plates had been straightened in a press, and had thus undergone some degree of cold-working. In zones where phosphorus segregation had taken place the bands came out very clearly on stressing the material, while in the parts where phosphorus was very low they do not appear at all.

K. Daeves, *A New Etching Reagent for Chromium and Tungsten Steels* (Stahl und Eisen, September 8, 1921, vol. 41, pp. 1262-1264). For the investigation of chromium and tungsten steels Honda and Murakami successfully used an alkaline solution of ferricyanide of potassium, which was found to react particularly on iron tungstide (Fe_2W) which when treated cold, turned from brown to blue. The present author conceived the idea of making a further study of the effect of ferricyanide of potassium on iron-chromium-carbon alloys. After some preliminary trials the etching composition of the reagent was modified, and the following solution was found to give the best results :

20	grammes	ferricyanide of potassium
10	„	sodium hydroxide
100	„	water

The solution acts slowly when cold, but fairly rapidly when hot, forming ferrocyanide compounds. When used cold it is very suitable for detecting the carbide constituent of the eutectic of chromium steels, and thus indicating whether the limit of solubility has been exceeded, which should be avoided in any structural material. The reagent is to be recommended for high-speed steel. When used hot it gives a strongly-defined colouring to the secondary cementite and to the cementite lamellæ of the pearlite in tungsten steels.

W. Velguth, *Improved Method of Etching for Microstructure* (Chemical and Metallurgical Engineering, September 21, 1921, vol. 25, pp. 567-568). Ordinary etching gives very flat results, and better orientation is revealed by cleaning specimens electrolytically in a caustic solution, or in a solution of sodium thiosulphate and then etching electrolytically in acid. Bright, clear, and well-coloured results can be obtained by these means.

A. Portevin, *The Use of very Slow Cooling for the Micrographical Study of Alloys and the Structure of Tungsten Steels* (Comptes Rendus, April 18, 1921). The advantages of slow cooling are that the structure of the alloys appears on a larger scale, permitting projection on the screen with relatively low magnification, and sometimes new, unsuspected equilibrium structures are seen.

P. Oberhoffer, *Metallographic Methods of Detecting the Previous Treatment of Mild Steel* (Stahl und Eisen, September 1, 1921, vol. 21, pp. 1215-1217). In explanation of the appearance of various micro-

graphs, the author is able to show whether annealing was carried out at or below the A_{c1} point or above A_{c3} . One micrograph shows pearlite islands surrounded by clearly marked ferrite areas, which are separated from the residual ferrite by definite crystal boundary lines, but stand out in relief, giving a kind of ragged appearance to the structure. It is explained that this particular structure is a sure indication that annealing has been carried out at a temperature between the A_{c1} and A_{c3} points.

Macroscopic Examination of Metals (Chemical and Metallurgical Engineering, August 24, 1921, vol. 25, pp. 334-335). The American Society for Testing Materials has proposed routine methods for the macroscopic examination of metals, indicating the mode of cleaning and polishing, the solutions to be used in etching, and the manner of taking sulphur prints. The methods proposed are reproduced.

R. Stotz, *Application of Metallography in the Foundry* (Giesserei Zeitung, July 5, 12, 1921, vol. 18, pp. 207-211, 215-220). A lecture giving information on the use of metallography generally and the lessons to be learned therefrom.

V. M. Goldschmidt, *Crystallography and the Constitution of Metals* (Zeitschrift für Metallkunde, October 1921, vol. 13, pp. 449-455). A general study of the crystal properties of metals, dealing with the form and structure of crystals and their characteristics. The properties of the crystals of the metallic element, and the crystal forms of certain metal compounds are set forth in tabular form. The forces of the space lattice are treated of as being the basis of the mechanical properties of a metal.

F. Osmond (posthumously by A. Portevin), *Introduction to the Study of Crystalline Deformations* (Revue de Métallurgie, May 1921, vol. 18, pp. 290-299). Osmond left instructions that his unpublished work was to be destroyed. The present work, however, consists of notes which he gave his pupil, Portevin, to help him in investigations on crystal deformation, and do not, in Portevin's opinion, come under the ban. They deal with the mechanism of slip, and have an added interest from the fact that, so far as crystal structure go, they lead to some of the same conclusions recently reached by radiographical means, and show that Osmond's view of the structure of α -iron and γ -iron foreshadowed the space lattice structure now assigned them.

A. Westgren and A. E. Lindh, *The Crystalline Structure of Iron and Steel* (Zeitschrift für Physik und Chemie, 1921, Parts 3, 4, pp. 161-210). The authors find that α -iron has a space-centred cubic lattice (Tammann's 9-point lattice) and β -iron has the same structure, showing that the latter is not a modified form of iron. Austenite and γ -iron have a surface-centred cubic lattice (Tammann's 14-point lattice). Martensite and high-speed steel hardened at 1275° have space-centred lattices.

Z. Jeffries and R. S. Archer, *The Crystalline Structure of Metals* (Chemical and Metallurgical Engineering, May 4, 1921, vol. 24,

pp. 771-778). The authors give a brief definition of crystallinity and discuss the methods used in X-ray analysis of crystal structure.

W. Rosenhain, *The Hardness of Solid Solutions* (Proceedings of the Royal Society, Series A, vol. 99, pp. 198-202). Employs the latest conceptions as to lattice structure to explain hardness in solid solutions of metals and of metalloids in one another. In such solutions it is suggested that atoms of the solvent replace those of the solute and that differential hardness would vary with the resulting distortion in the space lattice and consequent increase in internal energy. Anything which tends to hinder free occurrence of slip will increase hardness and lower ductility, even slight distortion of the space lattice structure by the presence of "dissolved" atoms of another metal would hinder slip on the crystal "planes."

Z. Jeffries and R. S. Archer, *The Slip Interference Theory of the Hardening of Metals* (Chemical and Metallurgical Engineering, June 15, 1921, vol. 24, pp. 1057-1067). The authors present a complete theory of the mechanism of hardening, and conclude that the inherent cohesion of the pure metals is far in excess of values obtained for tensile strength. Mechanical failure under stress is ordinarily premature because of the presence of crystallographic planes of weakness, or potential slip planes. Any structural condition which interferes with slip on these planes of weakness increases the strength and hardness of the metal. Furthermore, every known method of hardening metals can be referred to this principle of "slip interference." In a pure metal the most simple source of increased hardness is grain refinement, which introduces slip interference at the grain boundaries due to the different orientations of the adjacent grains, and especially in fine grained metals, to the disorganised or amorphous metal between the grains. Cold working introduces slip interference by the fragmentation of the grains and the production of amorphous metal. The hardness and strength of amorphous metal itself is due to the absence of the planes of weakness characteristic of crystals. Slip within grains is opposed by the presence of a strong constituent at the grain boundary, providing that if the strong constituent is brittle, its shape and size are not such as to lead to effective weakness due to eccentricity of loading. Effective hardening is obtained by slip interference within the grains, due to the presence of hard constituents uniformly distributed in the form of very fine particles.

A. Sauveur, *A Discussion of the Slip Interference Theory of Hardening* (Chemical and Metallurgical Engineering, September 14, 1921, vol. 25, pp. 509-512). A critical enumeration of the assumptions upon which the Jeffries-Archer theory is based. More evidence is required before it can be taken as proved that hardness is due to sub-microscopic grain size, and that cementite in solid solution is dissociated. The contention that an intermetallic compound cannot exist in a metal in a state of solid solution is also one which requires further evidence before it can be accepted.

H. Styri (Chemical and Metallurgical Engineering, August 24, 1921, pp. 313-314) thinks it reasonable to conclude that in hardened steel cementite is in solution in the traces of γ -iron left after most of the α -iron has formed.

A. Westgren, *The Slip Interference Theory of the Hardening of Metals* (Chemical and Metallurgical Engineering, October 5, 1921, vol. 25, p. 641). Comments on the views of recent writers, and particularly on those of Jeffries and Archer, and points out that molecules or grains of Fe_3C certainly act as more efficacious keys, producing slip interference in the ferrite crystals, than could free carbon atoms. The influence of amorphous metal is described as very much overrated.

A translation of the paper by Z. Jeffries and R. S. Archer, *Crystal-line Structure of Metals*, has been published (Revue Universelle des Mines, Bulletin, October 1, 1921, vol. 11, pp. 65-76).

D. J. McAdam, jun., *The Constitutions of Martensite and Troostite* (Chemical and Metallurgical Engineering, September 28, 1921, vol. 25, pp. 613-618). A contribution to the space lattice theories of constitution and to the slip interference theory of hardening. Jeffries and Archer's views on the effect of temperature on grain coalescence in ingot iron seem to be confirmed by recent experiments, and it is pointed out that if the term "martensite" is to apply only to the constituent in which allotropic expansion, and not carbide contraction, has occurred, such constituents, in some hyper-eutectoid steels, should be known as "hyper-eutectoid troostite." Martensite consists of α -iron with austenitic carbide in suspension. In troostite, this carbide has undergone carbide contraction to form the smallest cementite particles capable of independent existence.

A. A. Blue, *An Occurrence of Nitrogen in Steel* (Iron Age, July 7, 1921, vol. 108, pp. 1-5). The results are given of a microscopic examination of a forged steel rod that had been left accidentally in the flue of a heating furnace for a period of two months. The examination revealed the needle structure generally accepted to be typical of iron nitride.

R. Ruer, *Study of the Iron-Carbon Compounds* (Zeitschrift für anorganische Chemie, July 27, 1921, pp. 249-261).

P. Oberhoffer and K. Daeyes, *A Study of the so-called Double Carbide Chromium Tungsten Steels* (Stahl und Eisen, November 11, 1920, vol. 40, pp. 1515-1516). The object of the investigation was to determine quantitatively by microscopic methods the influence of chromium and tungsten on the limit of saturation of γ -iron.

K. Daeyes, *Limits of Solubility of Carbon in Ternary Steels* (Zeitschrift für anorganische Chemie, August 8, 1921, pp. 55-74). The study is divided into two parts, the chromium-iron-carbon system, and the tungsten-iron-carbon system. The report contains the full results of the investigation referred to above.

S. Valentiner, *The Core of the Atom* (Stahl und Eisen, April 7, 1921, vol. 41, pp. 465-472). A dissertation on the nature and constitution of the atom.

F. Oppenheimer, *Some Suggestions regarding the Mechanical Design*

of *Microscopes* (Journal of the Royal Microscopical Society, June 1921, pp. 134-140).

Fusion Point of Nickel.—W. P. White, *The Latent Heats of Fusion of Nickel and Monel Metal* (Chemical and Metallurgical Engineering, July 6, 1921, vol. 25, pp. 17-20). A redetermination, giving, in the case of nickel, 73 calories per gramme, a figure differing greatly from the 56 calories per gramme found by Wüst, *Thermal Constants of Technical Methods* (Verein deutscher Ingenieure, Forschungsarbeiten, 1918, No. 204). For monel metal the latent heat of fusion was found to be 68 calories, which is in close agreement with that found in the case of nickel.

Acid Resisting Alloys.—R. Walter, *Thermal Reactions of Silicon and their Practical Application* (Zeitschrift für Metallkunde, May 1921, vol. 13, pp. 225-230). In the making of silicon alloys certain elementary thermal reactions occur which the author has utilised in the production of high silicon alloys of complete chemical stability. He demonstrates that such alloys as tantiron and ironac suffer the defect of instability owing to the fact that they are prepared by a purely physical process which cannot be relied on to yield with certainty a correct chemical compound. By making use of what he terms the silico-thermal reaction, the heat developed by the reaction provides a cheap and rapid method of melting, and he obtains an alloy in a condition of perfect equilibrium, corresponding to the formula Fe_3Si . A certain amount of carbon is added to the liquid alloy after cooling somewhat, and it is treated so that the carbon is disseminated as finely divided graphite. Certain precautions are necessary to control the behaviour of the carbon, concerning which no particulars are given. In any case, however, a machinable silicon alloy with great resistance to acid attack has been developed, to which the name thermisilid has been given, which is now being used for all kinds of castings for use in the chemical industry. It is claimed that the troubles due to brittleness and porosity, which are usually characteristic of high silicon castings, have been entirely overcome.

F. Rittershausen, *Steels for the Chemical Industry* (Zeitschrift für angewandte Chemie, August 9, 1921, vol. 34, pp. 413-420). Chrome-nickel steels containing between 18 and 14 per cent. chromium and 5 to 20 per cent. nickel show very little loss in weight after heating at 1200° C. for twenty-five hours, and none at all when immersed in 10 per cent. nitric acid for fourteen days. They are, however, attacked by sulphuric and hydrochloric acids. Other effects of the addition of chromium and nickel in varying proportion to steel are described, and the structure and properties of steels specially manufactured by Krupp for the chemical industry are discussed.

Protective Coatings for Iron and Steel.—B. T. Sweely, *Acid Resistance of Enamelled Utensils* (Journal of the American Ceramic Society,

1921, vol. 4, pp. 407-412). Experiments with enamelled ware have shown that the surface of the layer of enamel which was uppermost during firing and cooling was readily attacked by acid, indicating that the more soluble materials tended to rise to the surface in firing. Enamelled utensils should therefore be fired in an inverted position.

N. Deane, *Notes on Enamels for Cast Iron* (Foundry Trade Journal, August 4, 1921, vol. 24, p. 86). The influence of various materials used in the production of enamel is briefly discussed.

N. Deane, *Preparation of Enamels* (Foundry Trade Journal, August 25, 1921, vol. 24, pp. 154-155).

C. E. Siebenthal and A. Stoll, *Cadmium in 1920* (United States Geological Survey: Mineral Resources, 1920, Part I.). Puts on record the field offered for the use of cadmium as a rust preventer. A process has been developed in America for electro-plating iron and steel articles with cadmium.

S. O. Cowper-Coles, *Protective Metallic Coatings* (Paper read before the Engineering Conference, Institution of Civil Engineers, June 30, 1921). Metallic coatings for the protection of iron and steel from corrosion are of two kinds: electro-positive coatings, and electro-negative coatings. The advantages of electro-positive zinc coatings, applied by the four usual methods, namely dipping, sherardising, electro-zincing, and spraying, are considered.

W. Lange, *Metal Coatings as a Protection against Rust* (Zeitschrift für Metallkunde, June 1921, vol. 13, pp. 267-275). A description is given of experiments during the war to determine the relative values of lead, tin, and aluminium coatings as a protection for steel surfaces against corrosion. Various methods were employed for coating steel specimens with these metals, and a series of corrosion tests were made of which the results are given.

The Galeco Rust-Proofing Process (Iron and Coal Trades Review, July 22, 1921, vol. 103, p. 105). The apparatus employed in the Galeco process, in which rust proofing is brought about by a special chemical and metallic compound which undergoes very moderate heat treatment when in contact with the articles being treated. A unit comprises a gas-coke-fired furnace fitted with forced draught, a container in the form of a mild steel tube to hold the material to be treated, and a separator for cleaning the treated material. No particulars are given of the special compound used in the process.

L. Guillet, *Methods of Protecting Metals, and "Calorisation"* (Revue de Métallurgie, Mémoires, May 1921, vol. 18, pp. 283-289). The coating, for protective purposes, of iron and steel with aluminium. It is conducted by heating the articles to be coated in a non-oxidising atmosphere, in contact with powdered aluminium and a chloride. A rotary oven used. The process is applicable both to cast and to rolled and wrought metal, but a superior coating is produced on the latter. The coating is very hard and somewhat brittle.

A. V. Farr, *Calorising as a Protection for Metals* (Paper read before

the Engineers' Society of Western Pennsylvania: Forging and Heat Treating, July 1921, vol. 7, pp. 384-386). The recent developments and applications of calorising are dealt with.

P. Nicolardot, *Progress of Metallisation* (Chimie et Industrie, June 1921, vol. 5, pp. 619-635). A detailed account of the Schoop process, and the plant and methods required in its application.

F. Grès, *Protection of Iron against Corrosion* (Bulletin Officiel de la Direction des Recherches et des Inventions, No. 8; reviewed in Age de Fer, May 31, 1921, vol. 37, pp. 1063-1064). An account of anti-rust coatings and preservatives, with special reference to the nature of corrosion, and the composition of special alloys intended to withstand rusting. Reference is made to the protective influence of bichromate and chromate salts in oil paints.

Corrosion.—J. Newton Friend, *A New Theory of the Corrosion of Iron* (Paper read before the American Electrochemical Society, September 1921). After discussing the known facts and theories, and the phenomena of rusting, the author puts forward an auto-colloidal catalytic theory, which postulates the corrosion as starting by the formation of colloidal ferrous hydroxide, which by contact with the air flocculates to hydrated ferric hydroxide, which latter is alternately reduced by contact with iron and oxidised by contact with air, thus continuing the corrosion.

F. N. Speller, *Prevention of Corrosion of Iron and Steel in Water* (Paper read before the American Electrochemical Society, April 1921: Chemical and Metallurgical Engineering, June 8, 1921, vol. 24, pp. 1009-1012). The strength of the corrosion attack depends upon the quantity of oxygen contained in the water. Some mechanical and chemical methods for removing air from water are indicated.

F. N. Speller, *Control of Corrosion in Iron and Steel Pipe* (Mechanical Engineering, October 1921, vol. 43, pp. 661-662). As a protection against external corrosion, the best medium is a melted bituminous mixture in which the pipes are dipped, after which a strip of fabric saturated in the same mixture may be bound spirally around the pipe. The principal factors which determine the rate and character of internal corrosion are the composition, temperature, and rate of flow of the water; the best means for the prevention of internal corrosion consists in the de-aeration of the water by either mechanical or chemical means.

G. Paris, *The Corrosion of Iron and its Prevention by the Degasification of Water* (Chimie et Industrie, July 1921, vol. 6, pp. 11-32). An exhaustive account of anti-corrosion methods as applied to iron and steel subjected to the action of water or of water vapour. A description is given of the various theories of corrosion and the method suggested for preventing it is the preliminary treatment of water to expel all oxygen and other gases dissolved therein, these being the active agents in corrosion.

D. Ellis, *Iron Bacteria in Relation to Incrustation of Pipes* (Paper read before the British Association, September 14, 1921: Engineering, September 23, 1921, vol. 112, pp. 457-458). The occurrence of iron bacteria in water-pipes is discussed. A study of their physiology has shown that acid waters are more favourable to the growth of iron bacteria than alkaline waters. They can multiply independently of the presence of iron, but if they multiply in the presence of iron they further the oxidation of ferrous to ferric compounds. The character of the growths in iron pipes and the remedies for their removal are considered.

F. P. McKibben, *Some Examples of Corrosion of Reinforcing Steel* (Engineering News Record, September 29, 1921, vol. 87, pp. 531-532). Fourteen structures in which chemical action had caused steel rusting and partial failure of the concrete are enumerated.

R. Grun, *Reinforcing Bars for Blast-Furnace Slag Cement* (Stahl und Eisen, April 28, 1921, vol. 41, pp. 577-579). Results of laboratory experiments show that no appreciable rusting of iron bars takes place in alkaline cement materials, so long as the cement covering is airtight. Experience has shown that in reinforced concrete made with iron-Portland cement or Portland cement, the imbedded steel bars never corrode. Iron-Portland cement and slag cement are in all respects equally as safe as ordinary Portland cement, for use in making reinforced concrete.

A. R. Surface, *Copper in Steel and the Corrosion of Cars* (Scientific American, March 5, 1921, vol. 124, p. 185). The service records of cars having copper-steel plates and plain steel plates show that after six years of service the copper-steel plates were practically free from corrosion, while plain steel plates were severely corroded.

F. K. Bell and W. A. Patrick, *Influence of Copper on the Rate of Solution of Iron in Acids* (Journal of the American Chemical Society, 1921, vol. 43, pp. 452-465). The results of experiments on pure iron-copper alloys confirm those of other investigators. Alloys containing 0.1 to 5.0 per cent. copper were exposed to attack by 28.7 per cent. hydrochloric acid, and it was found the copper had a marked effect in retarding solution, as compared with pure reduced iron. The rate of solution of pure iron was retarded by mere contact with a piece of copper wire, platinum and silver having no effect. Experiments with 57 per cent. sulphuric acid gave erratic results. The behaviour of the alloys in strong acids cannot, however, be taken as conclusive of their behaviour in dilute acids.

H. Styri, *Rust Prevention by Slushing* (Paper read before the American Electrochemical Society, September 1921). It was found that rust develops on slushed balls and bearings under the slushing grease, and investigation showed that the preliminary for protection against rust by greases is a thorough cleaning of the steel parts by an aqueous solution, preferably by an oil emulsion which leaves a thin oil film for short time protection.

C. J. Morrison, *Embrittling Effect of Pickling upon Carbon Steel* (Iron Age, August 11, 1921, vol. 108, pp. 334-335). The microscopic examination of an ordinary black sheet, which was pickled in sulphuric acid and annealed for fifteen minutes at a temperature of 300° F., shows conclusively that the brittleness is due to the increase in the width of the junction lines between grains, and also that the annealing restores the metal to its original condition.

Electro-Deposition of Iron.—W. E. Hughes, *Researches on the Electro-Deposition of Iron* (Paper read before the American Electrochemical Society, September 1921). The author considers the electro-deposition of iron from sulphate solutions, chloride solutions, and sulphate-chloride solutions, and discusses various researches upon other solutions than these.

W. E. Hughes, *Progress in the Commercial Application of Electrolysis* (Electrician, November 18, 1921, vol. 87, pp. 640-642). The author discusses the commercial application of electro-deposition of metals.

Laboratory Appliances.—R. L. Templin, *An Extensometer Calibrating Device* (Chemical and Metallurgical Engineering, August 10, 1921, vol. 25, pp. 248-250). Describes and illustrates a calibration instrument, and method for checking makers' apparatus, and standardising and checking machines in current use.

Metallurgical Research in Russia.—N. T. Belaiew, *The Russian Contribution in the Nineteenth Century to the Metallurgy of Steel* (Journal of the Royal Society of Arts, November 4, 1921, vol. 69, pp. 833-836). A brief review of the work of Anossoff and Tschernoff.

CHEMICAL ANALYSIS.

Analysis of Iron and Steel.—L. C. Crome, *Estimation of Sulphur in Malleable Cast Iron* (Chemical and Metallurgical Engineering, August 10, 1921, vol. 25, pp. 247-248). Establishes the fact of discrepancies between the sulphur as found by evolution methods, and by oxidation methods, in the case of white irons. The sulphur must be present in two distinct forms, the evolution method only giving that present as ferrous and manganese sulphides. In any case the sulphur present in some other form does not exert the same prejudicial influence as that present as sulphides, and as the evolution method accurately determines the latter it suffices for all control laboratory routine.

Meurice, *The Volumetric Determination of Iron in the Presence of considerable Hydrochloric Acid* (Annales de Chimie Analytique et de Chimie Appliquée, 1921, vol. 3, pp. 23-25).

Bedin, *Some Modifications of the De Nolly Electric Apparatus for the Determination of Carbon in Ferrous Alloys* (Annales de Chimie Analytique et de Chimie Appliquée, 1921, vol. 3, pp. 15-16).

Colorimetric Estimation of Phosphorus in Iron and Steel (Foundry Trade Journal, July 21, 1921, vol. 24, p. 61). The method originated by M. G. Misson is described. It is based upon the yellowish-orange colouration produced when an excess of ammonium molybdate solution is added in the cold to a dilute solution of phosphorus and vanadium in nitric acid, a colouration the intensity of which is proportional to the amount of phosphorus present.

A. Ferni and P. Malaguti, *Detection and Estimation of Chromium in Steel* (Giornale di Chimica Industriale ed Applicata, 1920, vol. 2, pp. 559-561). The method of detecting and estimating chromium by oxidising it to chromic acid by means of nitric acid and lead peroxide has been adapted to its estimation in steel.

B. S. Evans, *A New Process for the Estimation of Small Quantities of Chromium in Steels* (Analyst, 1921, vol. 46, pp. 38-42).

G. E. F. Lundell and J. I. Hoffman, *Determination of Cobalt and Nickel in Cobalt Steels* (Journal of Industrial and Engineering Chemistry, June 1921, vol. 13, pp. 540-543). The method is based on the electro-deposition of cobalt and nickel in a solution freed from iron chromium and interfering elements such as tungsten, molybdenum, vanadium, and copper.

H. S. van Klooster, *Nitroso R.-Salt : A New Reagent for the Detection of Cobalt* (Journal of the American Chemical Society, April 1921, vol. 43, pp. 746-749).

L. J. Curtman and N. H. Hecht, *A Method for the Rough Estimation of Iron and Manganese in Systematic Qualitative Analysis* (Chemical News, June 3, 1921, vol. 122, pp. 254-255). The estimation of the iron is based on the property of SnCl_2 to bleach the deep red $\text{Fe}(\text{CNS})_3$ formed by adding KCNS to the FeCl_3 solution. The manganese is converted by sodium bismuthate in nitric acid solution to HMnO_4 , and the latter bleached by the use of a standard solution of H_2O_2 . Since the presence of either metal does not interfere with the determination of the other, it is unnecessary to effect their separation in this method.

Analysis of Ores and Refractory Materials.—*Analysed Iron and Manganese Ores: Methods of Analysis* (United States Bureau of Standards, 1921, Circular No. 21).

Tentative Method for Ultimate Chemical Analysis of Chrome Ores and Chrome Brick (Proceedings of the American Society for Testing Materials, 1920, vol. 20, Part I., pp. 647-651).

Analysis of Coal.—S. R. Illingworth, *The Analysis of Coal* (Colliery Guardian, April 15, June 3, 24, Sept. 2, vol. 121, pp. 1094-1095, 1598-1599, 1803-1804, vol. 122, pp. 658-659, 725). A series of articles from the author's book, describing methods for the proximate and ultimate analysis of coal, and the sampling and analysis of coke.

A. R. Powell, *Analysis of Sulphur Forms in Coal* (United States Bureau of Mines, 1921, Technical Paper No. 254). The author has investigated the applicability of the Powell and Parr method for the analysis of sulphur forms to a variety of coals, and to introduce, if necessary, certain refinements of analysis.

R. C. Smart, *Coal Dust Sampling and Methods adopted in Practice* (Paper read before the South Wales Institute of Engineers, May 31, 1921: Colliery Guardian, June 3, 1921, vol. 121, pp. 1593-1594).

A. Dessemond, *Determination of the Volatile Matters in a Coal* (Revue de l'Industrie Minière, Mémoires, July 1, 1921, pp. 451-456). Draws attention to some anomalies and inaccuracies in the methods usually employed to determine volatile matter, and proposes modes of obviating any doubt or discrepancy.

Analysis of Gas.—A. Thau, *The Determination of Benzol in Coke-Oven Gas* (Glückauf, May 28, June 4, 11, 1921, vol. 57, pp. 505-511, 529-536, 559-562). A number of known methods for the estimation of benzol in gases are described, and the practice adopted in different countries is compared.

NOTICES OF RECENT BOOKS PRESENTED TO THE LIBRARY.

AUSTIN, L. S. "*The Metallurgy of the Common Metals : Gold, Silver, Iron (and Steel), Copper, Lead, and Zinc.*" 8vo, pp. xvii+615. Fifth edition. New York : John Wiley & Sons, Inc. ; London : Chapman & Hall, Ltd., 1921. (Price 42s.)

[This work is devoted in general to the description of the processes for winning the metals gold, silver, iron, copper, lead, and zinc from their ores and refining them. The metallurgy of iron is dealt with only up to the point of the smelting of pig iron. Following the description of the ores, the fuels used in smelting them, and the materials of which the furnaces are constructed, consideration is given to the important question of sampling, for the determination of the exact value of the ore before treatment. Information is given on improvements and recent changes in smelting practice and the cyanidation of gold and silver ores. In a chapter on metallurgical thermo-chemistry the methods of determining thermic values are set forth with great clearness, and two useful tables of the heats of formation of Chemical Elements have been added. Great pains have been taken in explaining underlying principles, in supplying details of processes and of metallurgical equipment, and an important feature of the new edition is the complete revision of the notes on the costs of operation necessitated by the great advance in prices in the last few years.]

COLVIN, F. H., and K. A. JUTHE. "*The Working of Steel ; Annealing, Heat Treating, and Hardening of Carbon and Alloy Steel.*" 8vo, pp. x+255. New York and London : McGraw-Hill Book Co., Inc., 1921. (Price 18s.)

[The ever-increasing use of steel in all industries, and the necessity of securing the best results from the material used, renders it important to possess a thorough knowledge of its proper working, since it is the correct treatment rather than the quality of the steel itself, and the substances used in the composition of its alloys, which determine the suitability of the material for the purpose for which it is intended to be used. With this in mind the authors have drawn freely from their own experience and from the experience of others in the endeavour to present the best information available as to the methods of treating the various kinds of steel now in commercial use. These steels include low carbon, high carbon, and alloy steels for various purposes, and practice in the manufacture of steels for the automobile industry is dealt with in particular. Some valuable information is also given on the practice followed in Government Establishments in the preparation of steels used in the manufacture of small arms. The work forms a valuable source of information for those engaged in the special steel industry.]

GIOLITTI, F. "*Heat Treatment of Soft and Medium Steels : Theory and Practice of the Preliminary Heat Treatments designed to give Maximum Toughness to Steel used for Machine Parts.*" 8vo, pp. viii+374. Translated by E. E. Thum and D. G. Vernaci. New York and London : McGraw-Hill Book Co., Inc., 1921. (Price 30s.)

[The author is to be congratulated on the issue of an edition in English of his work originally published in Italian, thereby rendering accessible to the English-speaking countries the very valuable information contained therein. Metallurgists and metallographists have often been impressed with the fact that various impurities and additions to steel affect the properties of the finished material to a far greater extent than might be expected, judging from the amount in which they are present. On this subject Dr. Giolitti supplies precise data, which has hitherto been almost entirely lacking. His systematic study of the effect of non-metallic impurities on commercial heat treatment shows the great advantages to be gained by their elimination or suppression, and by controlling by suitable means such phenomena

as flaky fractures, brittleness, and unsoundness in steel parts. The work is of great usefulness if only for its insistence that the successful heat treatment of steel depends primarily upon the diffusion of carbon and other soluble substances contained, gaseous or solid.]

HALL, W. T., and R. S. WILLIAMS. "*The Chemical and Metallographic Examination of Iron, Steel, and Brass.*" 8vo, pp. v+501. Part I. The Mechanical Analysis of Iron, Steel, and Brass. Part II. The Application of Metallography to the Inspection and Sampling of Alloys. New York and London : McGraw-Hill Book Co., Inc., 1921. (Price 30s.)

[Modern methods of manufacture and the use of metals under conditions of severe strain demand additional information as to the constitution of alloys, which can best be obtained by the examination of polished specimens. This branch of metal inspection, in addition to methods of chemical analysis, is considered in this book.

Part I. deals with the Chemical Analysis of Alloys, and includes well-tested methods of analysis selected mainly from reports of the United States Bureau of Standards, or from papers of the American Society for Testing Materials. Although most of the standard methods of steel analysis are included, special attention is drawn to those methods which are both rapid and accurate.

Part II. considers the physical rather than the chemical inspection of metals, and describes the methods of preparation and examination of polished metal surfaces as an independent means of determining the quality of material, as well as an aid in getting representative samples for chemical analysis. A brief introduction to metallography, in so far as it applies to the inspection of alloys, is included.

The work forms a valuable contribution to the existing knowledge of analytical methods and of the constitution of metals and their alloys.]

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